2D SEISMIC DATA INTERPRETATION INTEGRATED WITH RESERVOIR CHARACTERIZATION OF BALKASSAR AREA,UPPER INDUS BASIN,PAKISTAN

BY

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CERTIFICATE

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DEDICATION

Every challenging work needs self-effort as well as guidance of elders especially those who were very close to our heart. My humble effort I dedicate to my sweet and loving parents and siblings. I dedicate it to a place where much of this was invented, elaborated, or pondered and where a friendship developed that even the writing of a dissertation could not spoil.

ACKNOLEDGEMENT

In the name of Allah, the most Beneficent, the most Merciful. All praises to Almighty Allah, the creator of universe. I bear witness that there is no god but Allah and Holy Prophet Hazrat Muhammad (P.B.U.H) is the last messenger of Allah, whose life is a perfect model for the whole mankind till the Day of Judgment. Allah blessed me with knowledge related to Earth. Without the blessing of Allah, I could not be able to complete my work as well as to be at such a place.

I am especially indebted to my dissertation supervisor Prof Dr.Mona Lisa for giving me an initiative to this study. His inspiring guidance and dynamic supervision helped me to complete this work in time. I pay my thanks to whole faculty of department of Earth Sciences especially the teachers and Senior students of Department of Earth Sciences especially Mr.Mubashir Rafique whose valuable knowledge, assistance, cooperation and guidance enabled me to take initiative, develop and furnishing my academic carrier. I am thankful to all my friends, my class fellows and senior students of Department of Earth Sciences. I also am thankful to my parents for giving me all kind of support throughout my academic carrier.

Abstract

Reservoir characterization using seismic and well data is a renowned technique within the content of hydrocarbon exploration. This study retains to the interpretation of seismic lines, wireline logs,rock physics and colored inversion for better visualization of important feature at reservoir level. The study area selected for this purpose is Balkassar area.

In this dissertation, Two-dimensional seismic interpretation has been carried out in upper Indus Basin, Balkassar area to find the subsurface geological conditions or in order to demarcate the Probable zone for the accumulation of hydrocarbons. The horizons were marked with the help of provided well information (Balkasar OXY-1). The interpreted faults on each seismic section indicate the area belongs to compressional regime. From the given sections we could recognize the sub surface structure which was faulted at limbs. Two way Time and Depth contour maps at the top of Chorgali,Sakesar and Patala were constructed that showed the sub-surface anticlinal 'Pop up' structure faulted at the limbs,which is one of the most favorable structure for oil and gas accumulation.

Analysis of geophysical borehole logs provides one of the best approache to characterizing rocks within borehole. we find out different properties of rocks (volume of shale, Porosity ,Permeability and hydrocarbon saturation) and combination of different log results helped us to find out hydrocarbon potential zones.To discriminate between different lithologies we cross-Plotted different parameters, this helped us to separate reservoir from shale.Lithology of reservoir was limestone with interclation of shaly limestone. Petrophysical analysis of Balkassar oxy-1 well showed that chorgali and Sakesar formations have hydrocarbon Potential and Some oil zones were recognized. The lower part of Sakesar Formation shows indication of maturity or reservoir shale. Rock Physics is a powerful tool for reservoir characterization,it is applied to confirm the Petrophysical result by observing the trend of elastic Properties in a zones of interest.

Seismic inversion results are also demonstrating that Chorgali act as a reservoir. The post stack color inversion is performed to confirm the leads location. On inverted section Chorgali shows low value of impedance i.e. strong indicator for the presence of hydrocarbons.

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CH#01 INTRODUCTION

1.1 Introduction to study area:

Hydrocarbon exploration is a backbone for the economy of developing countries like Pakistan. Exploration sector searching for the unexplored area, as the energy demand increases. Pakistan has high potential of hydrocarbons in its southern (Badin, Mari etc.) and Northern parts (Potwar Kohat Plateau).The Kohat-Potwar belongs to the category of extracontinental downward basin which account for 48% of the world known petroleum resources (Hasany & Saleem, 2001). The Potwar sub basin is dominated by the structural traps and mostly seismic data is incorporated for the delineation of this structure. The dissertation comprises of exploration result in Balkassar oil field. The study area "Balkasar" is situated about 105 km southwest of Islamabad in Chakwal District. Balkasar is located in upper Indus basin which is further categorized as a part of potwar sub_ basin (northern part). Mainly, the location of Balkassar is in the Central portion of Potwar sub-basin which basically represents the part of Himalayan foreland fold-and-thrust belt (Kazmi and Jan 1997). In north of the Balkassar oil field bikhari kallan, it shares border with Kalar Kahar in south, Chakwal city is situated towards east of it and Talagang is towards south. Its location Coordinates are 32˚55′60″N (Latitude) and 72˚39′0″E (Longitude).The estimated terrain elevation of the region is about 506 m above mean sea level (Khan et al. 1986).

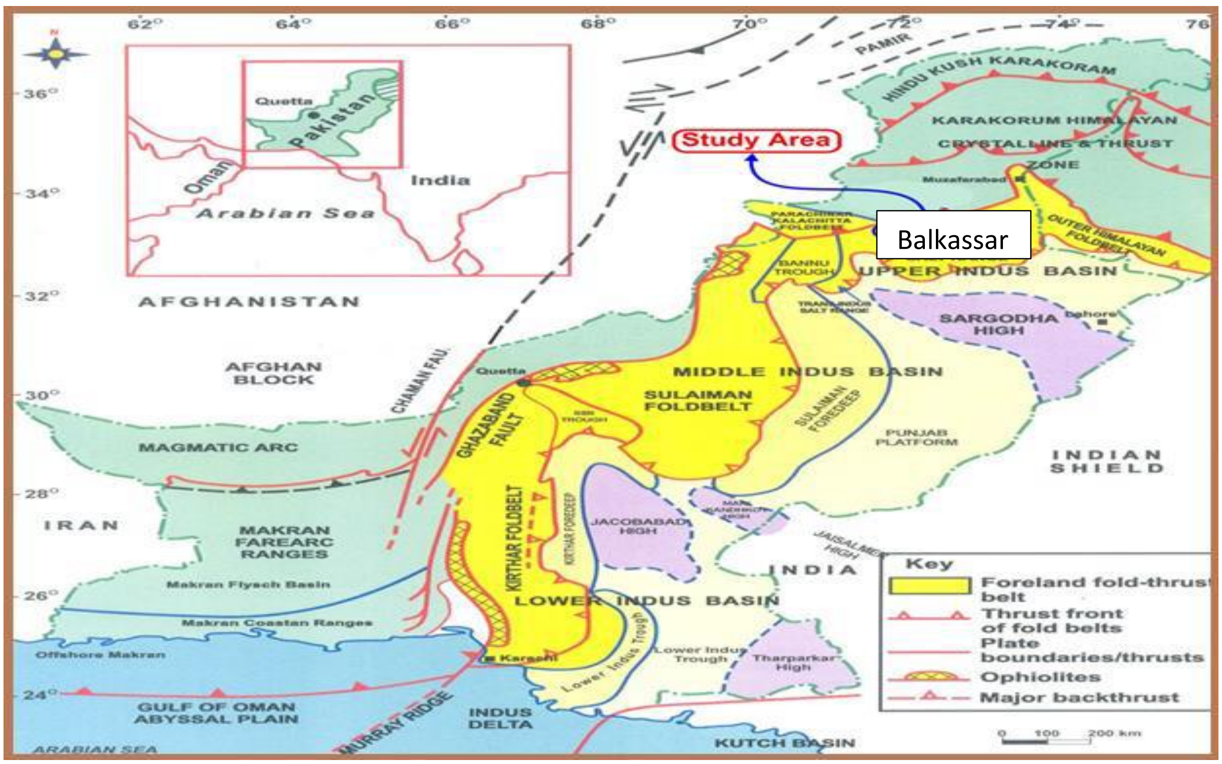

Figure 1.1: Location map of the study area (Highlighted)(Banks and Warburton,1986)

1.2 Physiography:

Forty-two physiographic regions can be defined in the Potwar study area including plateaus, flood plains, valleys, basins, hills, ridges, and ranges. The dominant physiographic feature in the study area is the highly dissected Potwar Plateau, which covers about 18,000 km2 in the central part of the area (Elahi and Martin, 1961).

The study area belongs to the Kohat-Potwar fold Belt which is in the north of Pakistan. The Kohat-Potwar Fold Belt covers an area of 36000 km^2. The area north of Salt Range is called Potwar Plateau owing to it is relatively constants elevation and it encompasses most of the drainage of the Soan River. Potwar is situated in the western foothills of Himalayan in the northern Pakistan. Potwar sub-basin is filled with thick Pre-Cambrian evaporates overlain by relatively thin platform deposits of Cambrian to Eocene followed by thick Miocene-Pliocene molasses. This whole section has been severely deformed by extremely intensive Himalayan Orogeny in Pliocene to Middle Pleistocene times

1.3 Data Description:

It includes the the seismic data & well data that are used for the the interpretation.

1.3.1 Seismic Data:

2D seismic survey are performed to acquire reflection sections. The seismic reflection data was acquired by POL in 1981 and processed by Oil and Gas Development Company Limited (OGDCL) in 1981.Base map shows the ten seismic reflection lines in which some lines are placed along the dip and some are placed along the strike of a structure. The detail description of lines shown by Table 1.1

1.3.2 Well data:

The well data includes the following files:

a) Balkassar OXY-1.LAS file .
b) Balkassar OXY-1. Txt.

These files store all the information about the logs run in the well and well tops. The Balkassar Oxy # 1 was the first exploratory well drilled by Oxy (Pak) in Pakistan. Balkassar OXY-1 well is adjacent to a line PJB-04.Further detail shown by Table 1.2

1.4 Base Map:

A map on which primary data and interpretation can be plotted. The base map is important for interpretation point of view because it depicts the spatial location of seismic section and also shows how seismic section are interconnected. It includes location of lease and concession boundaries, wells, and seismic survey points with geographic refrence such as latitude and longitude or Universal Transverse Mercator (UTM). Geophysicists typically use shot point maps, which show the orientations of seismic lines and the specific points at which seismic data were acquired, to display interpretations of seismic data.

The base map of the area is generated by plotting data in Universal Transverse Mercator (UTM, zone 42N) geodetic reference system. The base map given in figure 1.2 shows the orientation of the lines and position of well used for study.The lines under study are

- SOX-PBJ-04
- SOX-PBJ-06
- SOX-PBJ-09
- SOX-PBJ-10

SR.NO	SEG-Y	SP Range	Direction	Total length (km)	Nature/Trend
1	SOX-PBJ-01	85-215	SE-NW	12.6	DIP
2	SOX-PBJ-02	105-213	SE-NW	10.4	DIP
3	SOX-PBJ-03	99-218	SE-NW	10.3	DIP
4	SOX-PBJ-04	92-250	SE-NW	14.9	DIP
5	SOX-PBJ-05	123-248	SE-NW	11.8	DIP
6	SOX-PBJ-06	101-239	SE-NW	13.4	DIP
7	SOX-PBJ-08	106-290	NE-SW	18	Strike
8	SOX-PBJ-09	101-297	NE-SW	19.3	Strike
9	SOX-PBJ-10	99-289	NE-SW	18.4	Strike
10	SOX-PBJ-11	94-225	N-S	12.8	Oblique

Table 1.1: Description of seismic lines

Operator	**OXY**	**Province**	**Punjab**
Type	**Exploratory**	**Status**	**Abandoned**
Well Bore Name	**BALKASSAR-(OXY)-01**	**Concession**	
Longitude	**72 39 52.50**	**Latitude**	**32 56 38.80**
Spud Date	**20-June-1981**	**Completion Date**	**26-Sep-1981**
Depth Reference Elevation(m):	**535.53**	**Total Depth(m)**	**3130.60**
Depth Reference	**KB**		
List of Well Tops			
Formations	**Formation Age**	**Top(m)**	**Thickness(m)**
NAGRI	**PLIOCENE**	**0.00**	**478.82**
CHINJI	**MIOCENE**	**478.82**	**929.29**
KAMALIAL	**MIOCENE**	**1408.11**	**106.68**
MURREE	**MIOCENE**	**1514.78**	**906.74**
CHORGALI (BHADRAR)	**LOWER EOCENE**	**2421.52**	**45.72**
SAKESAR	**EOCENE**	**2467.24**	**135.63**
PATALA	**PALEOCENE**	**2602.87**	**21.34**
LOCKHART	**PALEOCENE**	**2624.20**	**35.05**
HANGU	**PALEOCENE**	**2659.25**	**27.43**
SARDHAI	**EARLY PERMIAN**	**2686.68**	**109.72**
WARCHA	**EARLY PERMIAN**	**2796.40**	**141.73**
DANDOT	**EARLY PERMIAN**	**2938.13**	**60.96**
TOBRA	**EARLY PERMIAN**	**2999.09**	**51.81**
KHEWRA SANDSTONE	**EARLY CAMBRIAN**	**3050.90**	**78.33**
SALT RANGE FORMATION	**PRE-CAMBRIAN**	**3129.229**	**0.77**

Table : 1.2 Description of Balkassar OXY-1 WELL

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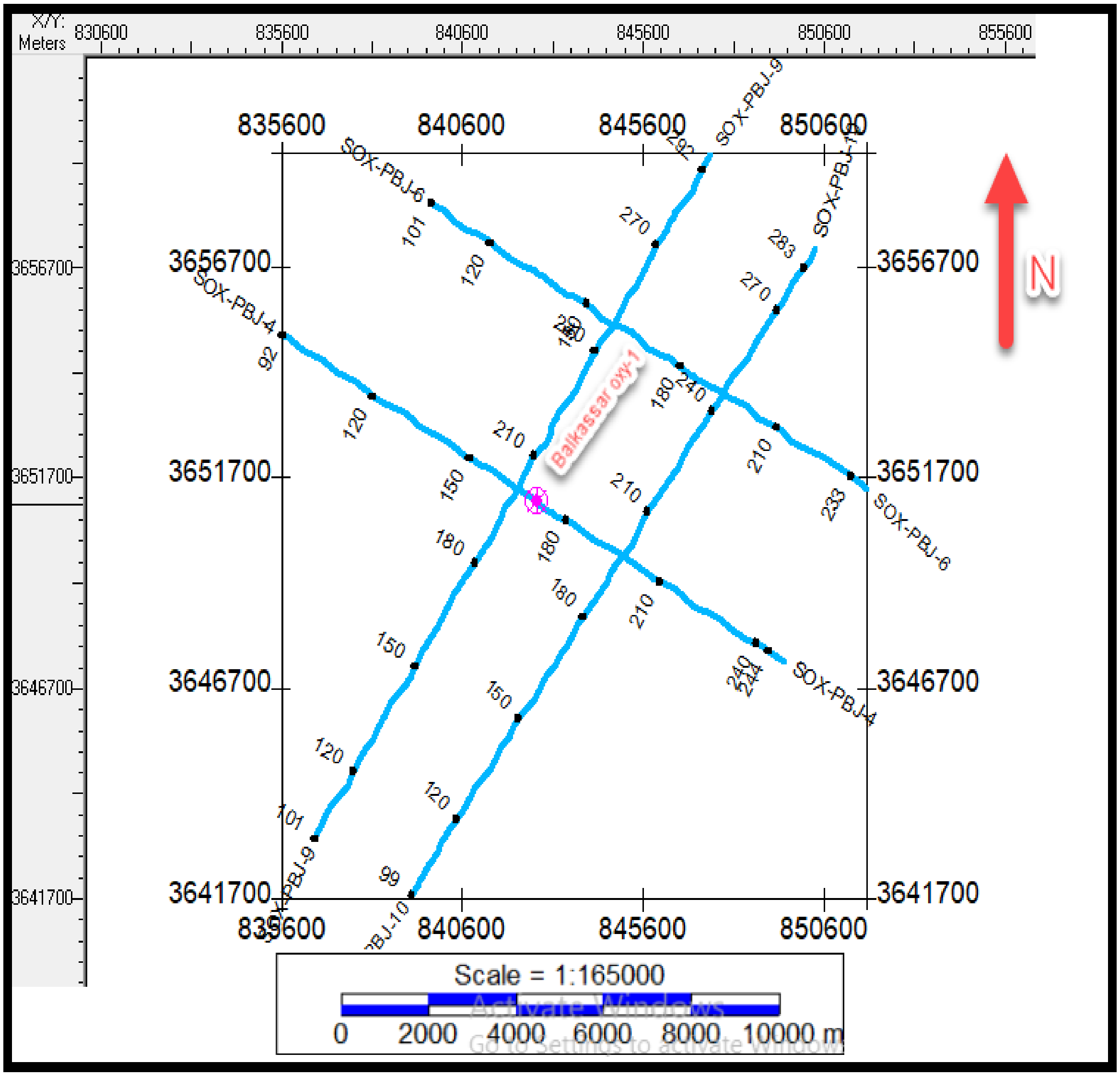

Figure 1.2 Base map of interpreted lines

1.5 Software Tools used:

To complete project and completion of this dissertation course work I used following software tools.

- IHS KINGDOM 8.6
- SMT KINGDOM 8.6
- SnagIt 11 (Editor)

1.6 objectives:

The main objective of this dissertation are:

- To understand the various steps involved in seismic reflection data interpretation.
- Detailed seismic interpretation for identification of the structures favorable for hydrocarbon accumulation.
- Facies Modeling for reservoir lithology identification.
- Petrophysical analysis for the identification of the reservoir types and various Petro-physical properties of reservoir encountered in study area.
- Rock Physics of reservoir formations to confirm the Petrophysical result.
- Colored Inversion of post stack data is carried out to confirm possible lead location after estimating the various reservoir properties.

1.7 Work Flow:

Basic work flow I have followed to achieve the objectives of dissertation are shown as under.2D seismic and well data are used for the subsurface interpretation. Steps which are used for the the Structurally model the subsurface are data loading, preparation of base map, fault polygon and horizon marking.Four horizons (chorgali, Sakesar, Patala, Basement) are picked by using synthetic seismogram and well tops and faults are also marked on seismic section on the basis of discontinuity and low amplitude.Time and depth contours map of these formations have generated using dynamic depth conversion plugin. Petrophysical and facies analysis are performed using well log data to find out the possible hydrocarbon bearing zone. Rock physics are also performed to confirm the Petrophysical results. At last full stack colored inversion is applied because it distributed the reservoir characterization over the whole seismic survey and also justified the Petrophysical result.

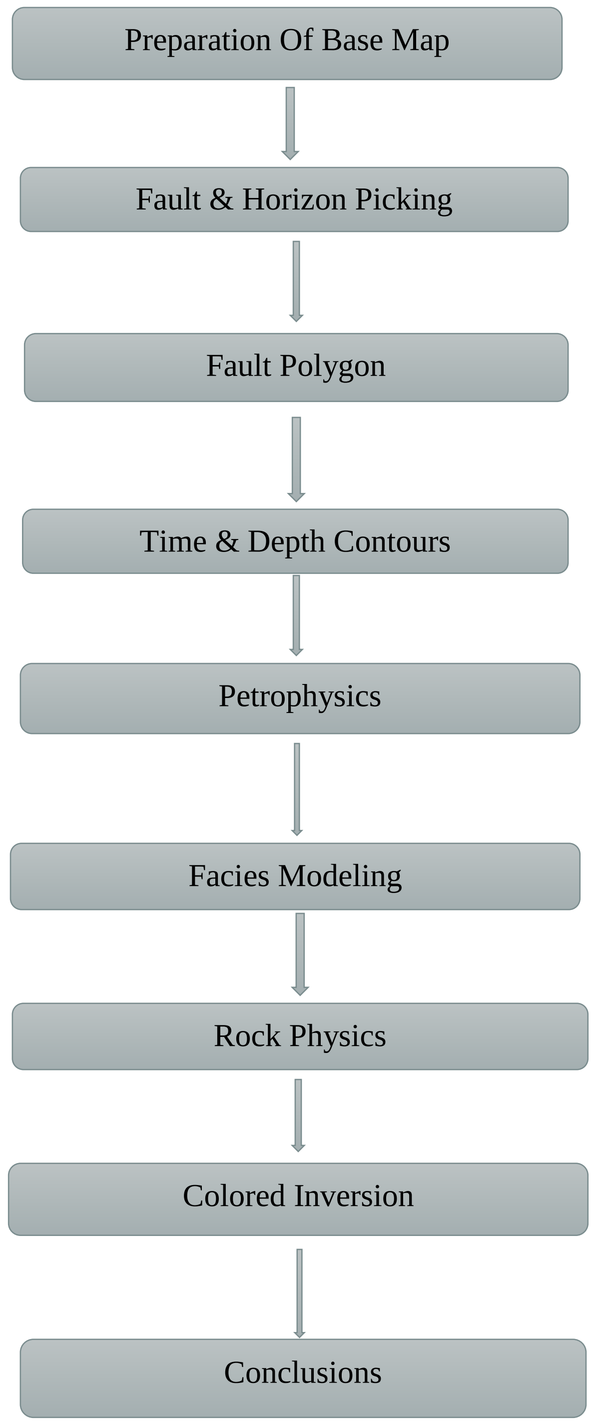

Figure 1.3 : Flowchart

CH#2 GEOLOGY AND STRATIGRAPHY

2.1 Introduction:

To understand the geology and structure of the area is the key for interpretation of seismic data. Interpreter must have background knowledge of geology about the area and its stratification, unconformities and major structures of area under study (Kazmi & Jan, 1997) to overcome the complexities such as same velocity affects can be generate from different formations. This chapter contains a brief description of geology, tectonic setting and stratigraphy of area under study.

2.2 Major Sedimentary basin:

Sedimentary basin are "Geologically depressed area with thick sediments in the interior and thinner sediments at edges"(Shah et al., 2009). In terms of genesis and different geological histories, Pakistan comprises three main sedimentary basins

- Indus Basin.
- Baluchistan Basin.
- Pishin Basin.

Indus and Baluchistan the basins evolved through different geological episodes and were finally welded together during Cretaceous/Paleocene along Ornach Nal/Chamman strike slip faults (Kazmi and Jan, 1997). The main sedimentary basins of Pakistan shown in a figure 2.2 given by Abdul Fateh et al., (1984) Also the further subdivision of the Indus basin is shown in the figure 2.1. Our study area lies in the potowar part of Indus basin.

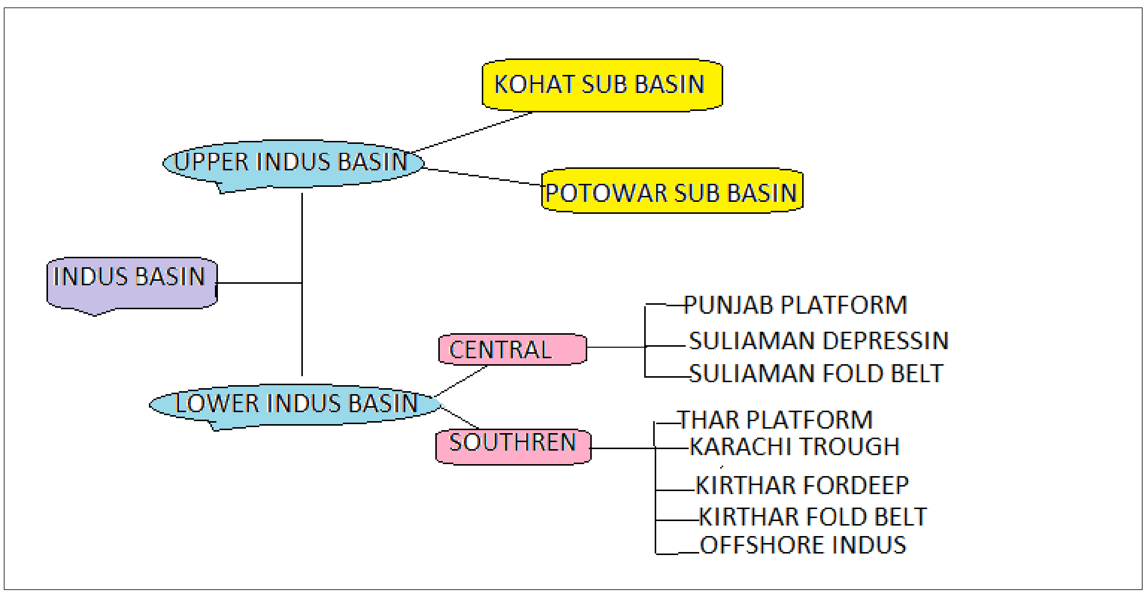

Figure2.1 Division of the Indus Basin (I B Qadri,1995)

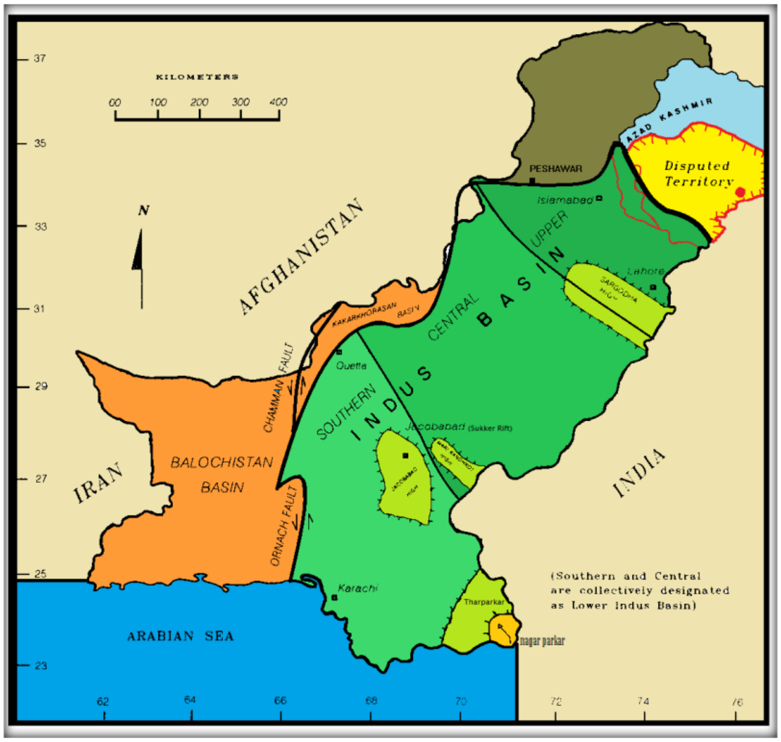

Figure 2.2 Sedimentary Basin of Pakistan (Fateh et al.1984)

2.3 Regional Tectonic Setting:

The building of Himalayan mountain process in Eocene triggered compressional syste.Northward movement of Indian plate is about 40mm/year (1.6 inches/yr.) and is colliding with Eurasian plate. 55 million years ago Indian plate collided with the Eurasian plate and building of Himalayan mountain belt 30-40 million years was formed in the North Western Pakistan and mountain ranges moved in the east west direction (Kazmi and Jan,1997). Being one of the most active collision zones in the world foreland thrusting is taking place on continental scale. It has created variety of active folds and thrust wedges with in Pakistan passing from Kashmir fold and thrust belt in North East, South West through the Salt range-Potwar plateau fold belt, the Suleiman fold belt and the Makran accretionary wedge of Pakistan. As far as the Indian plate is concerned which is subducting under the Eurasian plate at its Northern edge, a sequence of north dipping south thrusts are being produced. The shortening of crust caused a large amount of folds and thrust belt.The youngest basins in the Western Himalayan Foreland Thrust Belt are Kohat Plateau, Bannu Basin and Potwar Plateau which have compressive stresses and convergent tectonics. Pakistan is located at in the two domains Gondwanian and the Tethyan Domains (Kazmi& Jan, 1997). The south eastern part of Pakistan belongs to Gondwanian Domain and is supported by the Indo-Pakistan crustal plate whereas the northern-most and western areas of Pakistan fall in Tethyan.

Tectonically Pakistan is divided into (Qadri, 1995).

1. Northern Collision Belt.

2. Subduction Complex Association of Balochistan.

3. Chaman Transform Zone.

4. Ophiolites and Ophiolitic Melanges.

5. Platform Areas

The Potwar Plateau is comprises of less internally deformed fold and thrust belt having a width of approximately 150 km in N−S direction. The terrain in Potwar is undulated. Sakesar is the highest mountain of this region (1522 m). The Potwar is tectonically situated directly below the western foothills of Himalayas and falls in Potwar Plateau. In north it extends about130 km from the Main Boundary Thrust (MBT) and is bounded in the east by Jhelum strike-slip fault, in the west by Kalabagh strike-slip fault and in thesouth by the Salt Range Thrust (Aamir and Siddiqui, 2006).

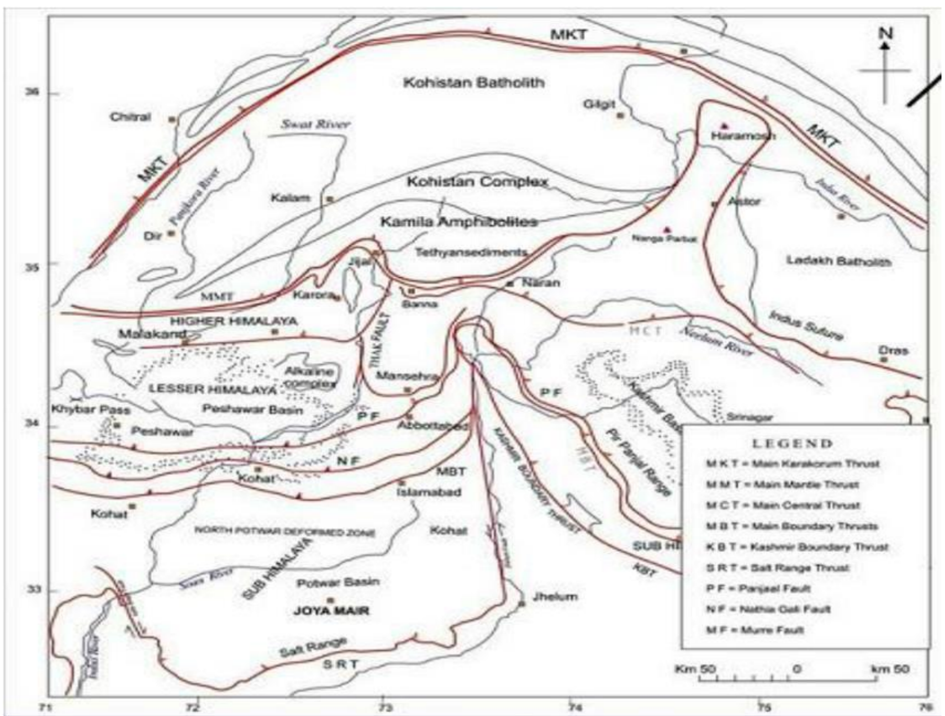

Figure 2.3 Tectonic map of Pakistan (Modified after Ghazanfar.1993)

2.3.1 Geological Boundries of potwar plateau:

The Potwar is bounded by the following two strike-slip and two thrust fault which are.

1 .Kalabagh Fault.

2 .Jhleum Fault.

3 .Salt Range Thrust.

4 .Main Boundary Thrust.

So our study area also lie in the potwar basin having the same geological boundaries.

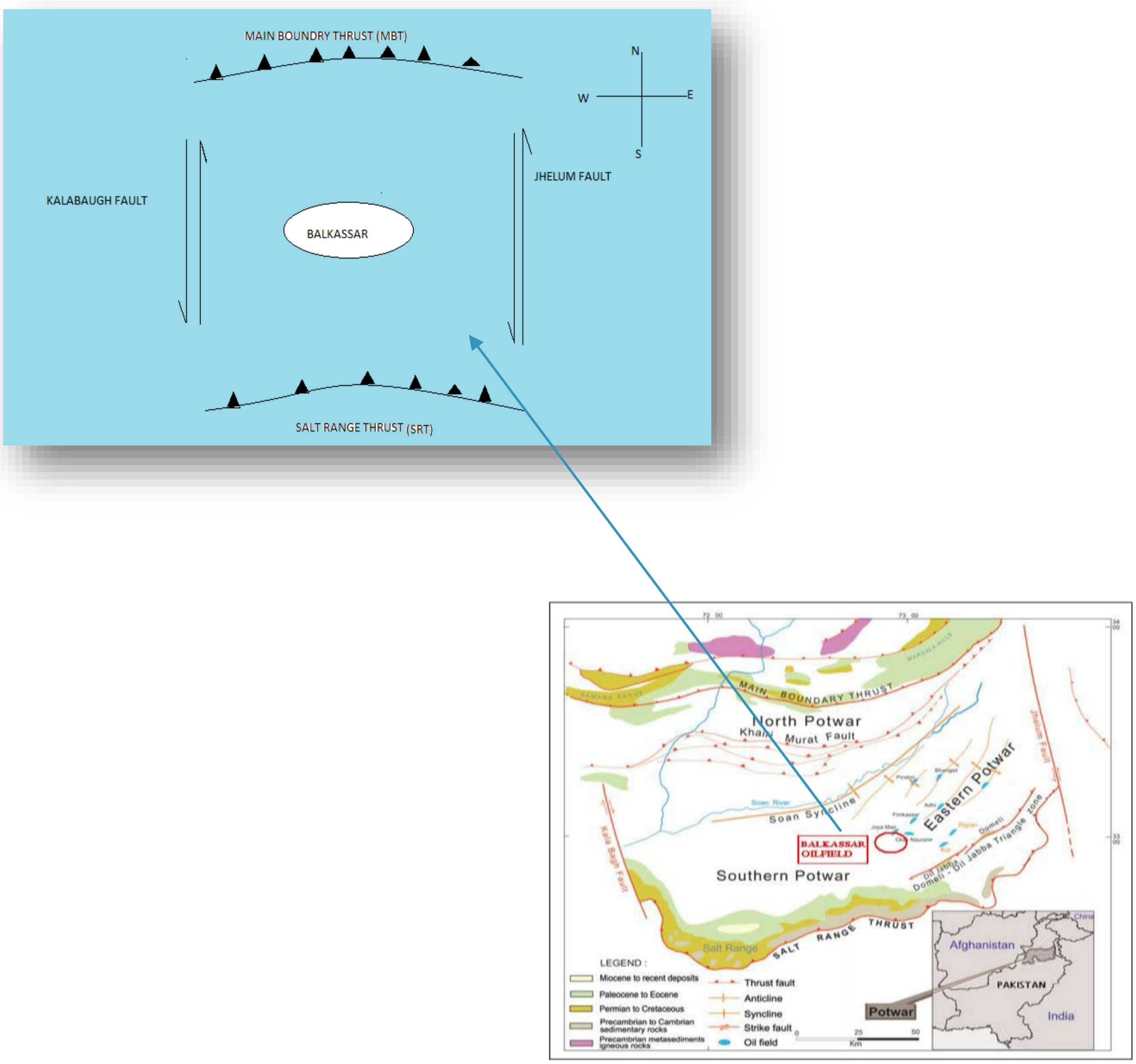

Fig 2.4 Structural and Tectonic map of Potowar Region. (After Khan et al. 1986 Gee,1989)

2.3.2 Tectonics Structures:

Tectonic features in Potwar are divided from South to North into three major tectonic elements (1) the Jhelum Plain, (2) the Salt Range and (3) the Potwar Plateau (Yeats and Lawrence, 1984). In Potwar large wedge of Phanerozoic rocks are thrusted over the Punjab plains along basal decollement in the Eo cambrian evaporite sequence of the Salt Range Fm .Basement in Sargodha is gently dipping northwards which does not cause structural deformation. South of the Soan River is nearly undeformed but is deformed on its northern and eastern margins. The potwar is divided into the following structural zones.

- Northern Potwar Deformed Zone (NPDZ).
- Soan Syncline.
- Eastern Potwar Plateau.
- Southern Potwar Plateau.
- Western Potwar Plateau.

Mainly, contractional folds and faults occur in the area; however, preexisting normal faults also occur in the crystalline basement (Pennock et al. 1989). The overall structural trend is east to west or northeast to southwest. In East Potwar salt core anticlines are separated by synclines. These structures are mostly bounded by hinterland and foreland verging faults, popup zones are thought to be formed due to strike slip movement. The northern part is more intensively deformed called North Potwar Deformed Zone (NPDZ) Normally, duplexes and imbricate thrusts occur in the NPDZ (Jadoon et al. 1999; Ghazi et al. in press), and the southern part of the plateau is relatively less deformed (Jaswal et al. 1997).

2.3.3 Structural Features :

The following structural features are found in study area (Pennock et al., 1989) .

- Tanwin Anticline
- Domeli Thrust
- Adhi-Gungril Anticline
- Chak-Naurang Anticline
- Soan Syncline
- Jhelum fault
- The Salt Range Thrust
- Popup anticline
- Triangle zone
- Salt cored anticline

2.4 Structure of study area:

Balkassar lies in Central piece of Potwar Sub-basin which is a piece of Himalayan foreland overlay and-push belt. This structure is situated on the southern appendage of Soan Syncline The Balkassar structure is a "anticlinal pop-up" structures created by both compressional and shear stress regimes. The Eastern flank is bounded by a regional thrust fault, the regionally trends NE-SW along one complex of fault-bend folds. It is becoming narrow towards north where a fault bounded syncline plunges into the middle of anticline and hence resulted in compartmentalization.

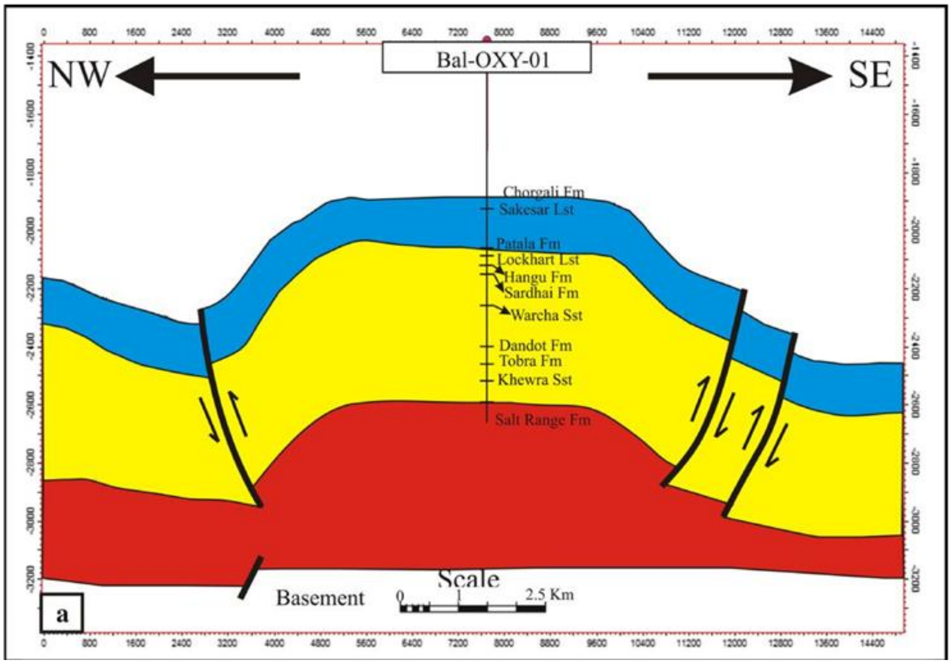

Figure 2.5 Balkassar Structure Model

2.5 Stratigraphy of the area:

Stratigraphic segment is separated into three unconformity-limited groups. These unconformities in the review zone are Ordovician to Carboniferous, Mesozoic to Late Permian, and Oligocene in age. These unconformities are difficult to identify in the seismic profiles due to complicated thrusting The Potwar sub-basin is filled with thick infra-Cambrian evaporite deposits overlain by relatively thin Cambrian to Eocene age platform deposits followed by thick Miocene-Pliocene molasse deposits. This whole section has been severely deformed by intense tectonic activity during the Himalayan orogeny in Pliocene to middle Pleistocene time. The oldest formation penetrated in this area is the Infra- Cambrian Salt Range Formation, which is dominantly composed of halite with subordinate marl, dolomite, and shales (Muhammad Aamir and Muhammad Maas Siddiqui,2006).

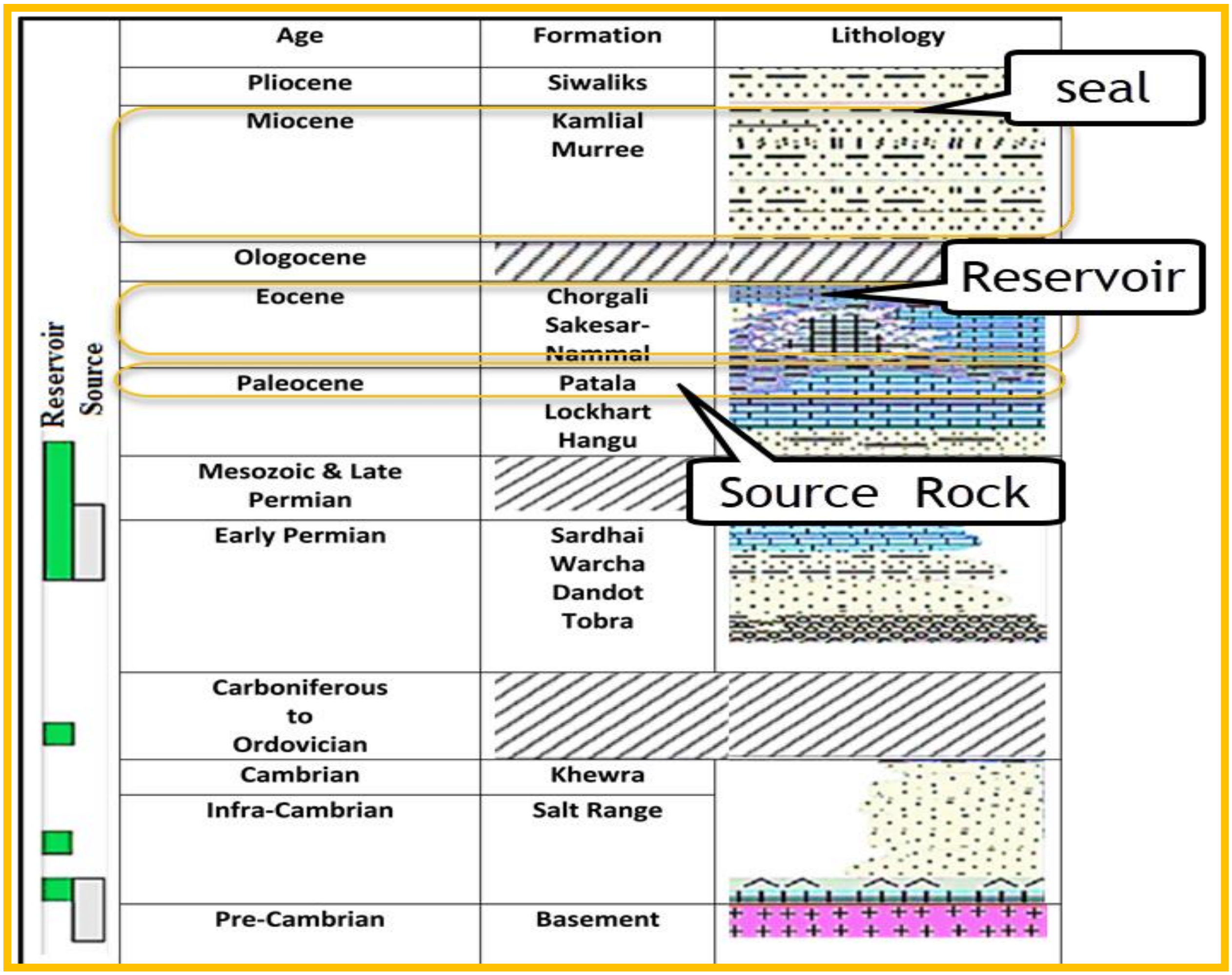

Figure 2.6 Schematic stratigraphic column of the study area(M.Farhana etal.)

The Salt Range Formation is best developed in the Eastern Salt Range. The salt lies unconformably on the Precambrian basement. The overlying platform sequence consists of Cambrian to Eocene shallow water sediments with major unconformities at the base of Permian and Paleocene. The Potwar basin was raised during Ordovician to Carboniferous; therefore no sediments of this time interval were deposited in the basin. The second sudden alteration to the sedimentary system is represented by the complete lack of the Mesozoic sedimentary sequence, including late Permian to Cretaceous, throughout the eastern Potwar area. In Mesozoic time the depocenter was located in central Potwar, where a thick Mesozoic sedimentary section is present. A major unconformity is also found between the platform sequence and overlying molasse section where the entire Oligocene sedimentary record is missing. The molasse deposits include the Murree, Kamlial, Chinji, Nagri, and Dhok Pathan Formations (Muhammad Aamir and Muhammad Maas Siddiqui, 2006).

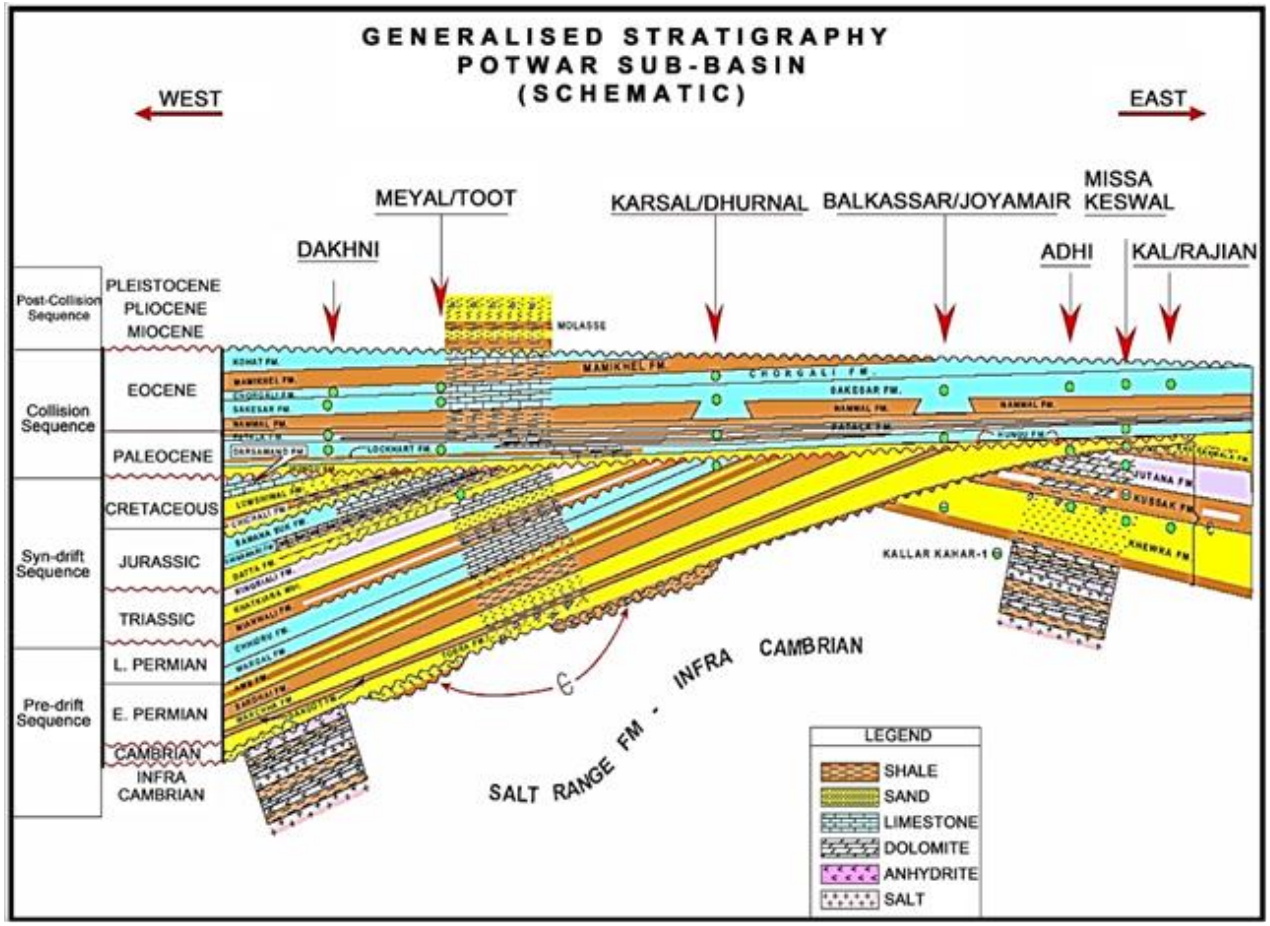

Figure 2.7 Subsurface geometry of Potwar Sub-Basin in relation to structure and entrapment

2.6 Petroleoum Prospectivity:

The Salt Range Potwar-Foreland Basin (SRPFB) belongs to the category of extra continental down warp basins, which accounts for 48% of the world known petroleum (Riva, 1983). Presence of continental margin, thick marine sedimentary sequence, potential source, and reservoir and cap rocks make this region suitable for suitable for hydrocarbon accumulation. It contains a thick overburden (about 3000 m) of fluvial sediments, which provide the burial depth and optimum geothermal gradient for seeps found in this area (Moghal et al., 2003). The (Salt range-Potwar foreland basin with an average geothermal gradient of 2 °C/100 m is producing oil from the depth of 2750-5200m (Shami & Baig, 2003).

2.6.1 Source rock:

Hydrocarbon Development Institute of Pakistan (HDIP), in collaboration with Federal Institute for Geosciences and Natural Resources (BGR) Hanover, Germany have identified a number of source rock horizons through Infra-Cambrian to Eocene in the Potwar Sub-basin and surrounding areas (F. Masood et al).

- These investigations suggest that the organic-rich shales of the Paleocene (Patala Formation) can be considered as the main seeker for sourcing the Potwar oil fields. In Potwar Basin, Patala shales of Paleocene have proven as the main source rocks. These organic shales were partly deposited in anoxic conditions prevailing Paleocene due to closing of the basin floor. Pre-Cambrian Salt Range Formation also contains oil shale intervals, which show source rock potential.
- Shales of Khewra Formation are of lacustrine to marine origin and contain woody, coaly to variously amorphous (with significantly woody herbaceous) kerogen, which are capable of generating paraffinic to normal crude and gas.
- Lokhart limestone has a fair amount of organic matter round about 1.4 % so it is considered as source rock to some extent, (Kadri, 1995).

2.6.2 Reservoir rock:

Paleozoic-Tertiary dominantly marine sedimentary rocks form petroleum systems in Potwar and are exposed in Salt Range along the Frontal Thrust.

- The cracked carbonates of Sakessar and Chorgali Formations are the major generating repositories in Balkassar.
- Khewra sandstone with porosity (10-12) %, Tobra, Dandot and Warcha formation at Adhi field.
- Amb and Wargal formations at Dhurnal field.

2.6.3 Seal rock:

The clays and shales of the Murree Formation additionally give effective vertical and horizontal seal to Eocene reservoirs (chorgali & sakesar) wherever it is in contact.

Traps:

Traps have been developed due to thin-skinned tectonics, which has produced faulted anticlines, pop-up and positive flower structures above Pre-Cambrian salt.

CH#3 SEIESMIC INTERPRETATION

3.1 Introduction:

Seiesmic interpretation and subsurface modeling are key skills used in oil industry.It is used to generate model and predictions about the properties and structure of subsurface. Seismic data interpretation has objective to get or extract all subsurface information from the processed seismic data. According to Dobrin and Savit (1988) interpretation is defined as

"The Interpretation is the transformation of the seismic reflection data into structural picture by the application of correction, migration and time depth conversion".

3.1.1 Approach used in Interpretation:

Kearey & Brooks (1984) have described two main approaches i.e. Stratigraphic analysis and structure analysis used in interpretation of seismic section.

- Structure analysis is the study of the reflectors geometry on the basis of reflection time.
- Stratigraphic analysis is the analysis of lithologically distinct depositional sequences.

3.1.2 Stratigraphic Analysis:

Stratigraphy analysis involves the delineating of seismic sequences, which represent the different depositional units, recognizing the seismic facies characteristic with suggest depositional environment. Analysis of reflection characteristic variation to locate the both Stratigraphy change and hydrocarbon depositional environment . The amplitude, velocity, frequency or the change in wave shape indicates hydrocarbon accumulation. Unconformities are marked by drainage pattern that help to develop the depositional environment. Reef, lenses, unconformity are example of Stratigraphy traps (Sheriff, 1999).

3.1.3 Structural Analysis:

In structural analysis main emphases is on the structural traps in which tectonics play an important role. Tectonic setting usually governs which types of the structure are present and how the structural features are correlated with each others so tectonic of the area is helpful in determining the structural style of the area and to locate the traps. Structural traps include the faults, folds anticline, horse and graben pop up, duplex, (Sheriff, 1999).I have followed the structural analysis approach for the interpretation of Balkassar area.

Structural interpretation usually includes the identification

- **Horizons**
- **Faults and Folds**

3.2 Structural Analysis of Balkassar:

Subsurface structural analyses in the present work were carried out through structural and lithological information provided by borehole data (Balkassar-oxy 1) and 2D seismic data (SOX-PBJ-04,SOX-PBJ-06,SOX-PBJ-09,SOX-PBJ-10).It depicts that severe thrust faults which confirm the compressional tectonic regime with anticlinal structure in the proposed area.

3.3 Work Flow:

The basic work flow for the interpretation of seismic data is preparing a base map by loading Navigation data and SEG-Y in software. Horizons of interest are marked manually. Faults are identified and marked on the basis of criteria for the recognition of discontinuties. Faults polygons are generated and horizons are contoured to find out structural highs and lows. Then time-depth contour maps of mark horizons are built to show the geometry of chose reflection events. Figure 3.1 shows the step used for seismic interpretation.

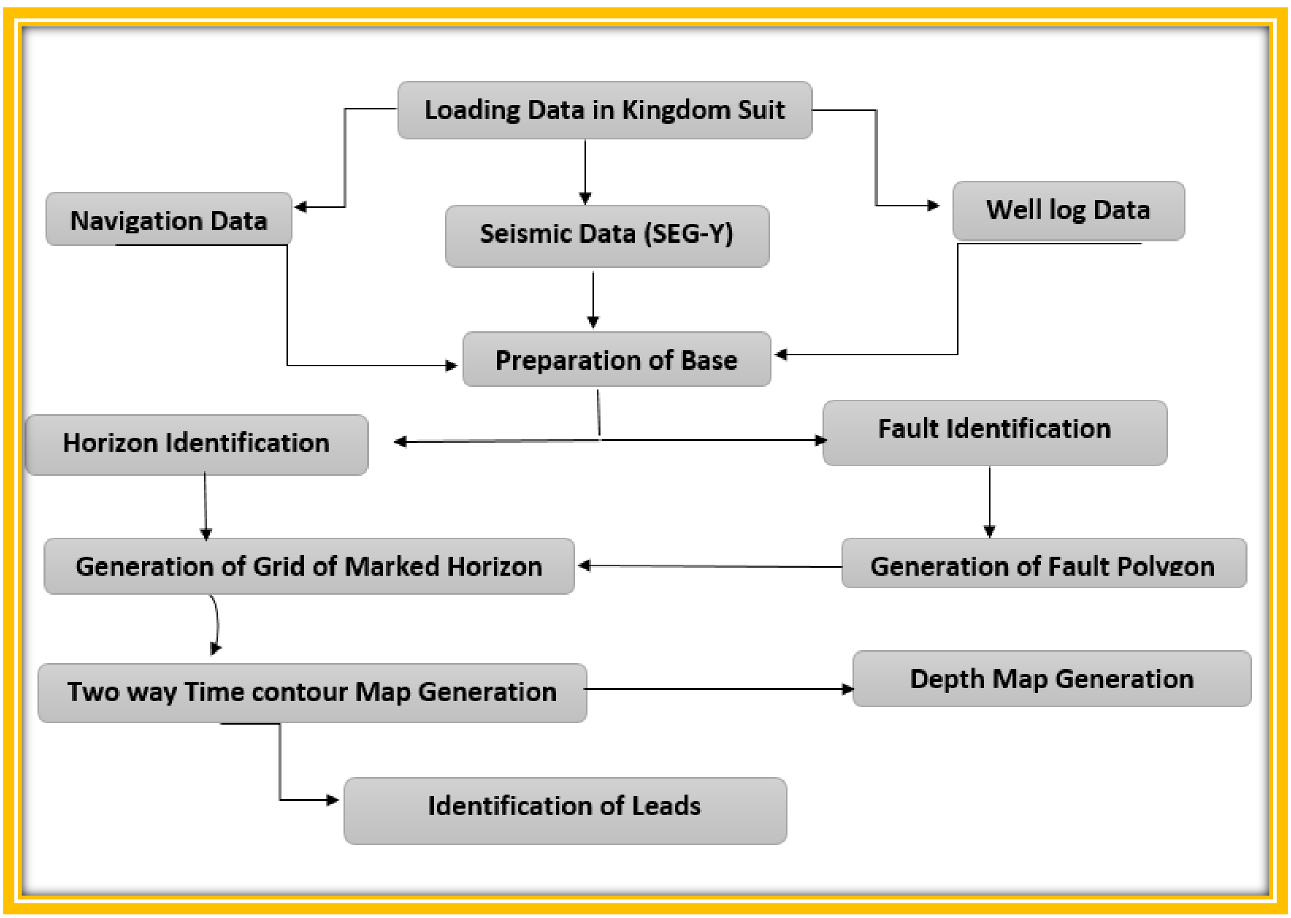

Figure 3.1: Workflow for Seismic data Interpretation

3.4 Synthetic Seismogram Generation:

Generation of synthetic seiesmogram is important in identifying the origin of seismic reflections seen on the seismic data. Accurate marking of horizons of interested area synthetic seismogram is generated by using Kingdom software at well location Balkassar OXY-01. For that Purpose, first acoustic impedance is require which is the product of Velocity and density .We use two well logs, Sonic (vp) and Density log (RHOB). Sonic gives us the delay in travel time and its inverse gives the velocity. Density log gives the density of formation in contact. The product of these give acoustic impedance that is further used for the extraction of reflection coefficient series and convolved with source wavelet. wavelet is extracted from seismic trace at well location and convolution of reflection coefficient series with wavelet forms a Synthetic seismogram.

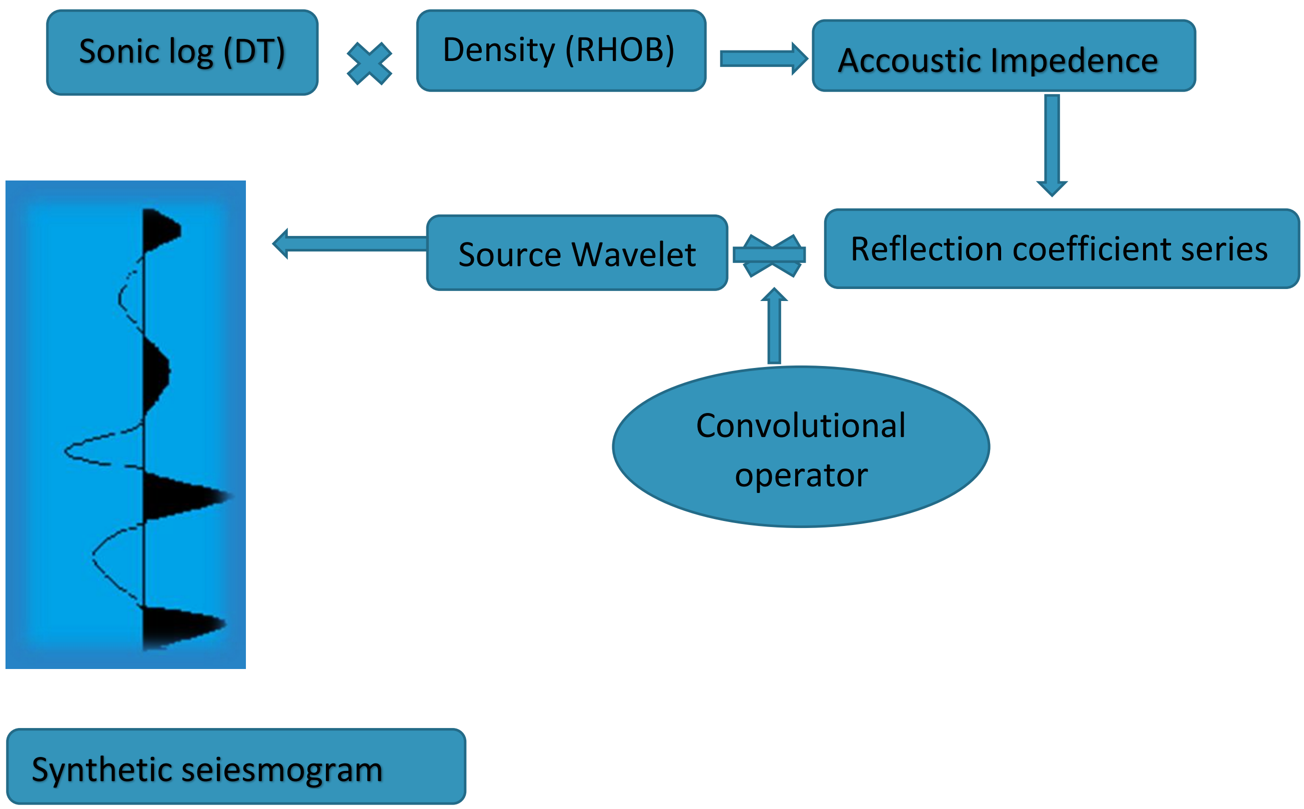

Figure 3.2 Basic workflow for generation of synthetic seiesmogram

3.5 Seismic to Well tie:

Well to seismic tie involves comparing the seismic data which is in time domain with well data in depth domain. An accurate synthetic seiesmogram is the key for performing well to seismic tie.

- Synthetic seiesmogram confirms our hypothesis and identifies horizons of interest.
- Polarity either positive or negative.

So, seismic to well tie are important for the accurate picking of horizons.

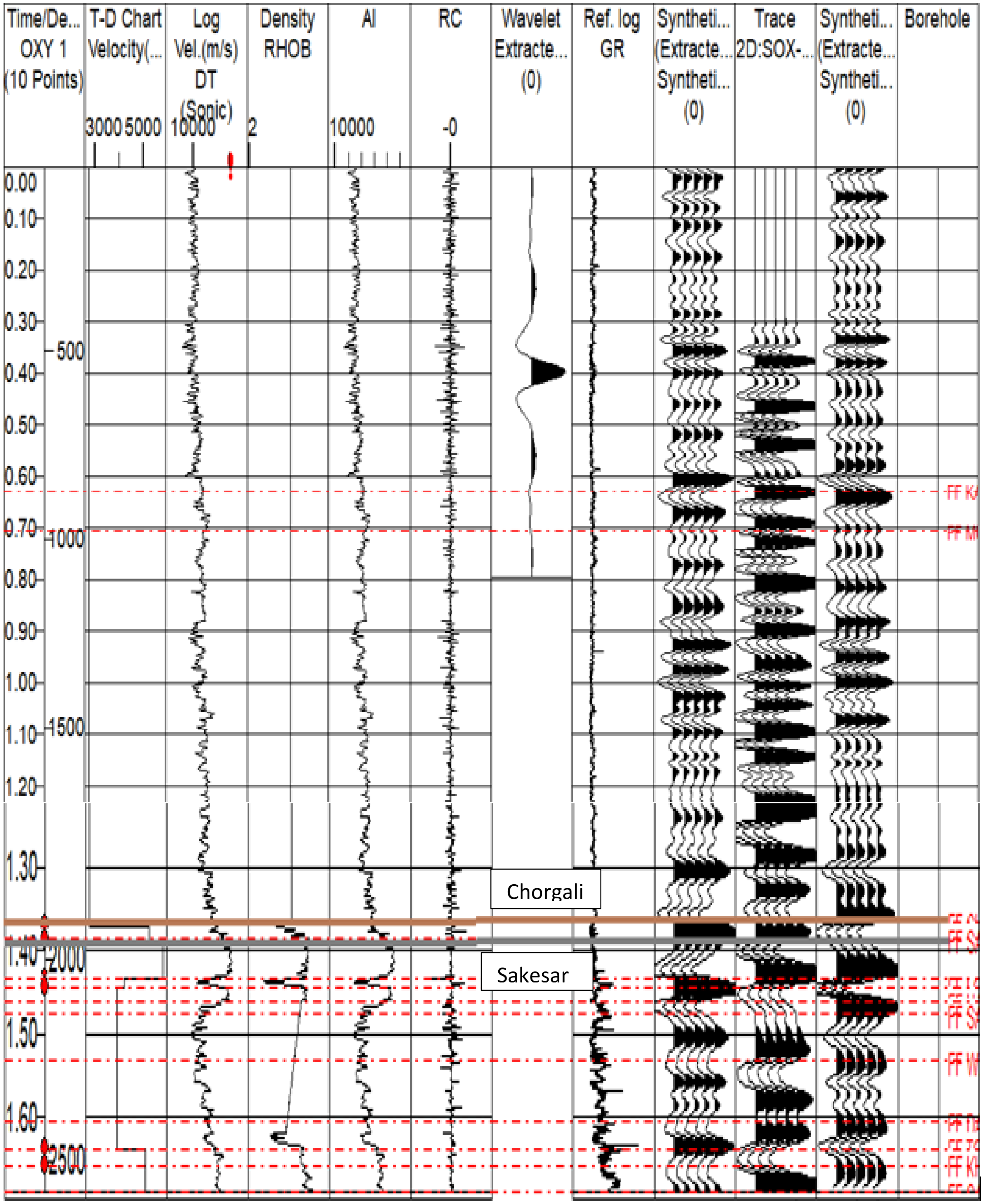

Figure 3.3 Synthetic seiesmogram of Balkassar oxy-1

3.6 Marking Faults:

Faults are marked on the basis of break in the continuity of the train of wavelets that indicate the distubance of area (fault presence). Fault marking on real time domain seismic section is quite a hard work to do without knowing tectonic history of area (Sroor, 2010).Another factor that indicate the presence of faults are

- Abrupt changes in dips
- Low Amplitudes

  On the basis of fault recognition factors four faults are marked on the seismic lines (SOX-PBJ-04,SOX-PBJ-06) that indicates that Balkassar is a structurally disturbed area and anticline 'pop up' structure is present bounded by F1 and F2

Fault Name	Fault Nature
F1	Reverse
F2	Reverse
F3	Normal
F4	Reverse

3.7 Marking of horizons:

Horizons are marked on the time section on the basis of synthetic seismogram, well tops and prominent reflection .Choosing the exact horizon time is sometimes difficult, since the bed boundary may not be on a peak or trough of the seismic trace. So, a synthetic seismogram is often used to calibrate these time picks. Generally horizons are marked by picking continuous wavelets. As the wavelets can appear mixed up so confusion can arise or due to any geological changes. Noises are the most common type of problem that is faced and they cause distortion. So, self-judgment of the interpreter along with knowledge and experience helps a lot in marking these horizons.Four horizons are picked on the basis of available information (Well tops and synthetic seismogram of Balkassar OXY-01 has been used in this dissertation). Horizons names are assigned on basis of well tops of the well BALKASSAR_OXY_1. The following horizons were picked:

- Chorgali Formation.
- Sakesar Formation.
- Patala Formation.
- Basement.

Sr.NO	Formation name	Top(m)	Marking colour
1	Chorgali	2421.5	Purple
2	Sakesar	2467	Yellow
3	Patala	2602	Blue
4	Basement		Red

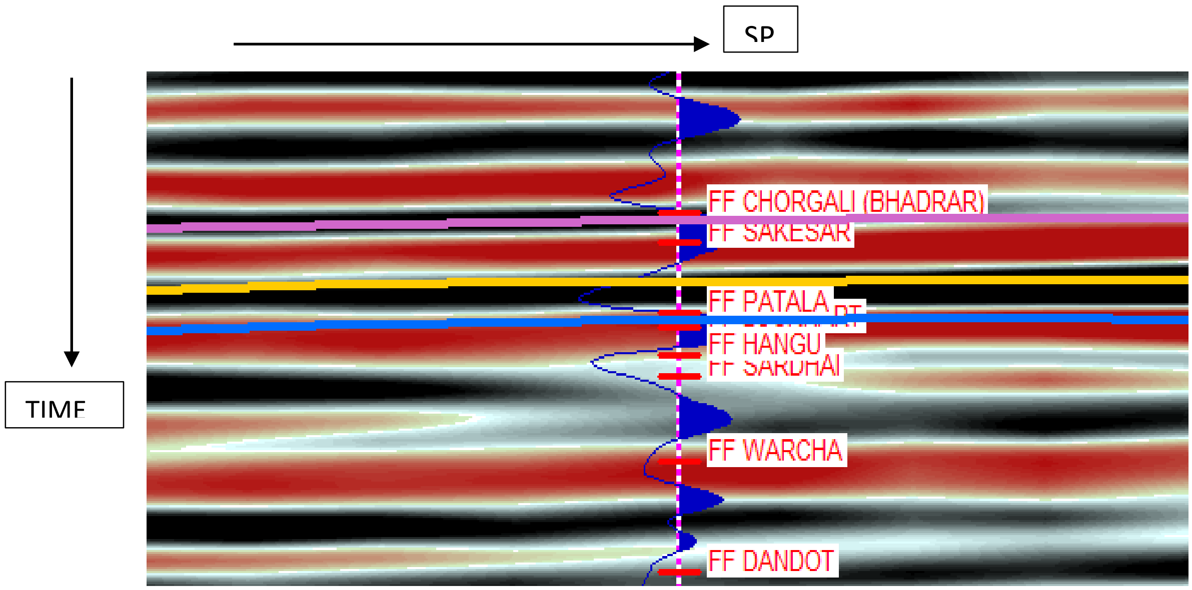

Figure 3.4 Synthetic seismogram overlaid on SOX-PBJ-04

3.8 Interpretation of seismic lines:

Interpretation of seismic lines and their figures are shown as under

3.8.1 Line SOX-PBJ-04:

PBJ-04 is our control line as the Balkassar-oxy-01 is located on it .It is SE-NW dip oriented line. Three reverse faults are marked F1, F2 and F4 in which F1 and F4 is a north-west dipping and F2 South-east dipping. Marked horizons (chorgali,Sakesar,Patala) are terminated along these faults and represent anticlinal 'pop up structure" which is bounded by the F1 and F2. That feature "anticline" are mainly due to Himalayan Orogenic Forces initiated the Salt diapirism which resulted in the development of bulge/ anticlinal structure in Balkassar area. Basement showing the the normal faulting which is marked by F3 which is probably the result of Permian Rifting. Figure 3.5 shows the interpreted time Section of PBJ-04.

3.8.2 Line SOX-PBJ-09:

PBJ-09 is a SW-NE strike oriented line. Control is transferred to it from PBJ-04. It passes through the crest of the Balkassar anticline, No major structure was found and simple straight horizons were marked because the strike line was parallel to the faults and no fault cut the strike line.

3.8.3 Line SOX-PBJ-06

Similarly control is transferred to PBJ-06 from PBJ-09.It is SE –NW dip oriented line but it lies to the north most out of these lines so in this region the tectonic forces are much intense. so,same extension of faults are found here (F1,F2,F3,F4),that represent the anticline “pop up” structure and normal faulting observed in Basement. Dip of the faults are almost same. Due to High tectonic forces one feature is observed here that not found in seismic line of PBJ-04 that is structure narrow down and fault bounded syncline plunge appear in the middle of the anti-cline which results in compartmentalization.

3.8.4 Line SOX-PBJ-10:

Last interpreted line is SOX-PBJ-10 and no faults are found there. Horizons are forming an asymmetric anticline whose limbs are gentle in the one side and somewhat steep in the another side.

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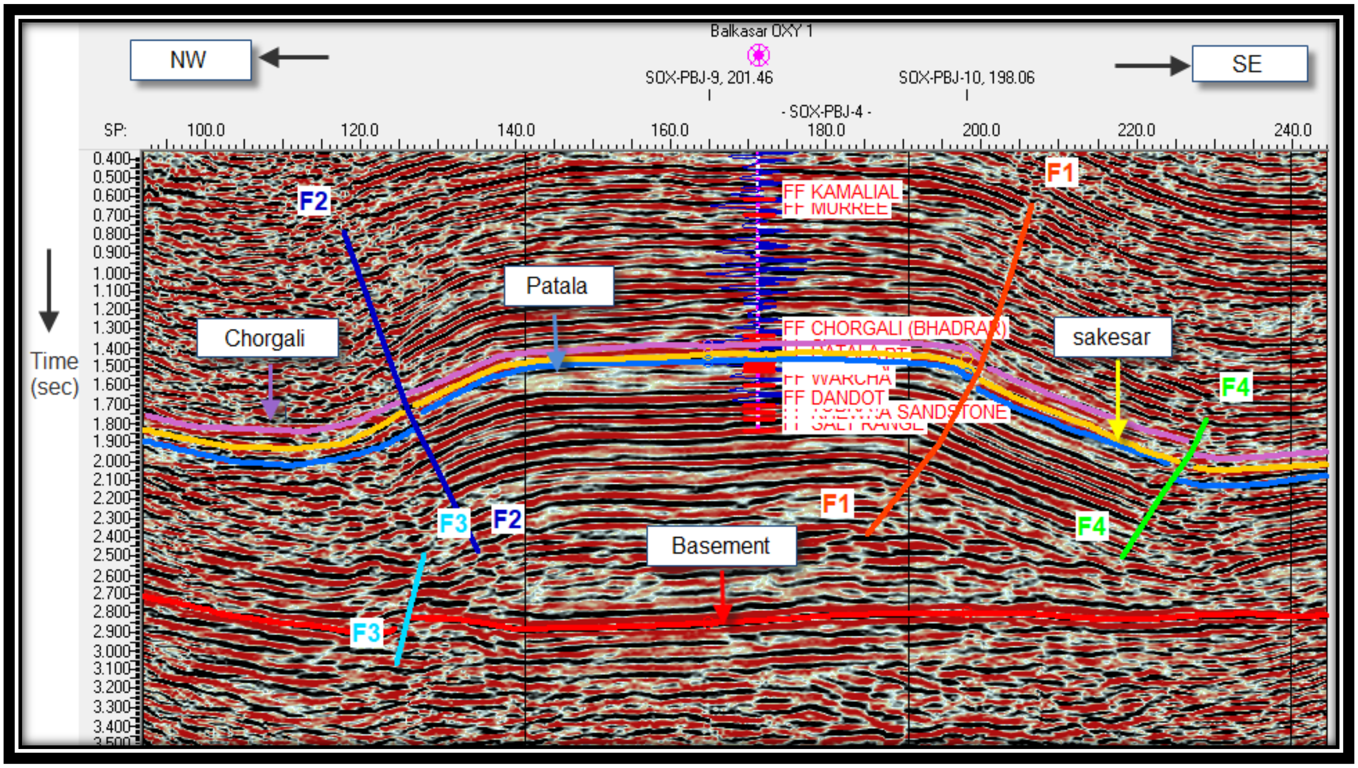


Figure 3.5 Interpreted seismic section, line PBJ-04 with synthetic Display

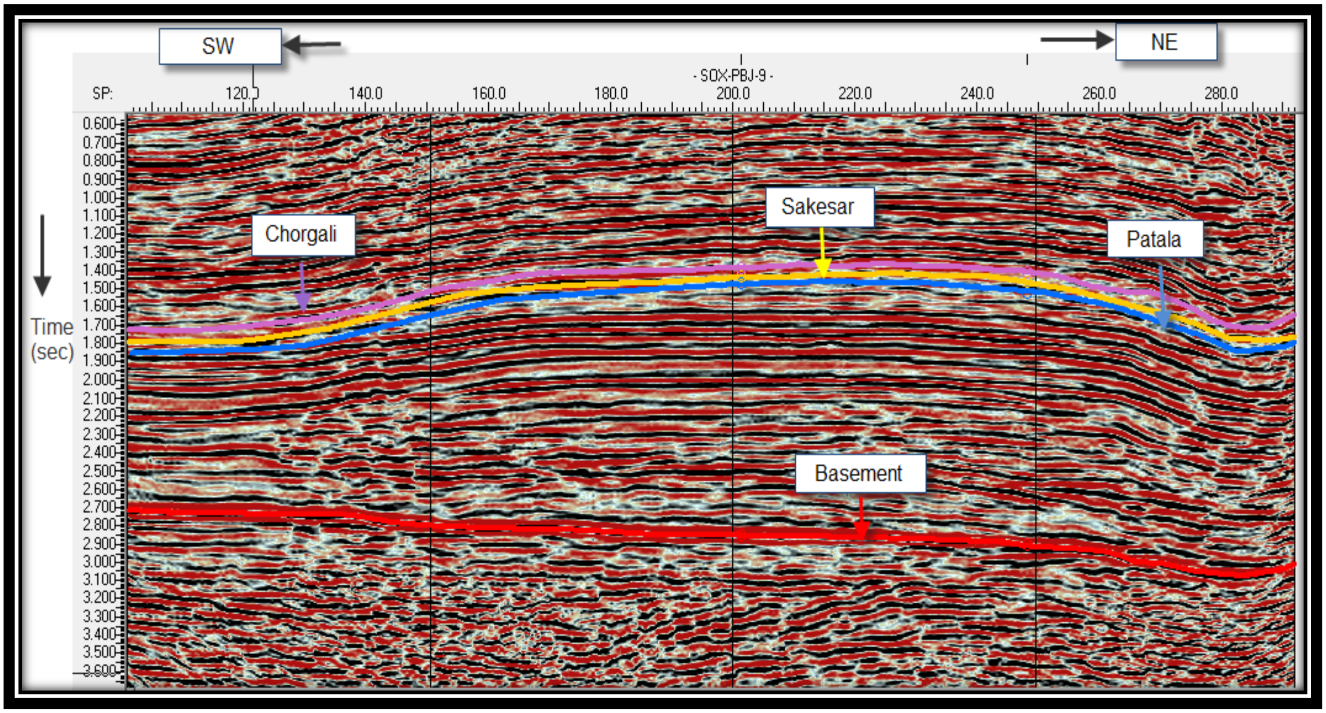


Figure 3.6 Interpreted seismic section, line PBJ-09

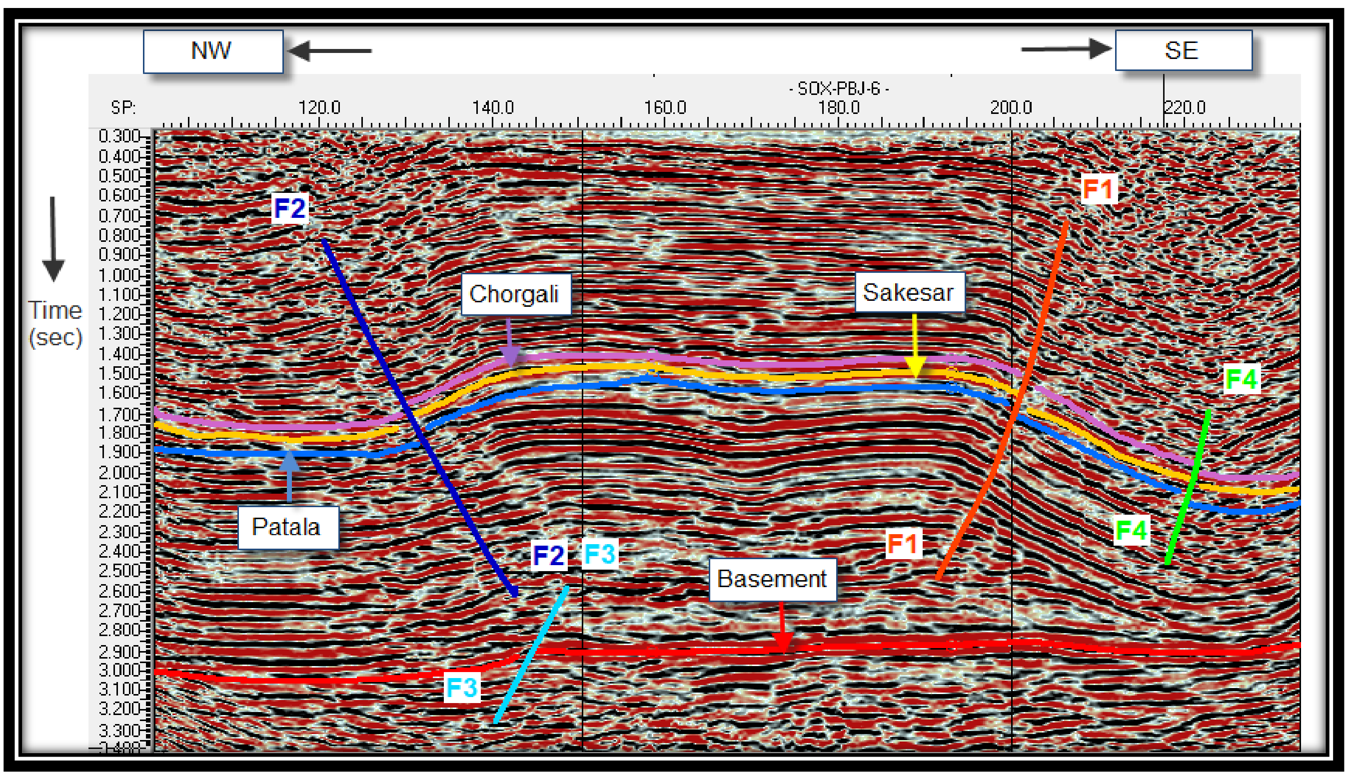


Figure 3.7 Interpreted seismic section, line PBJ-06

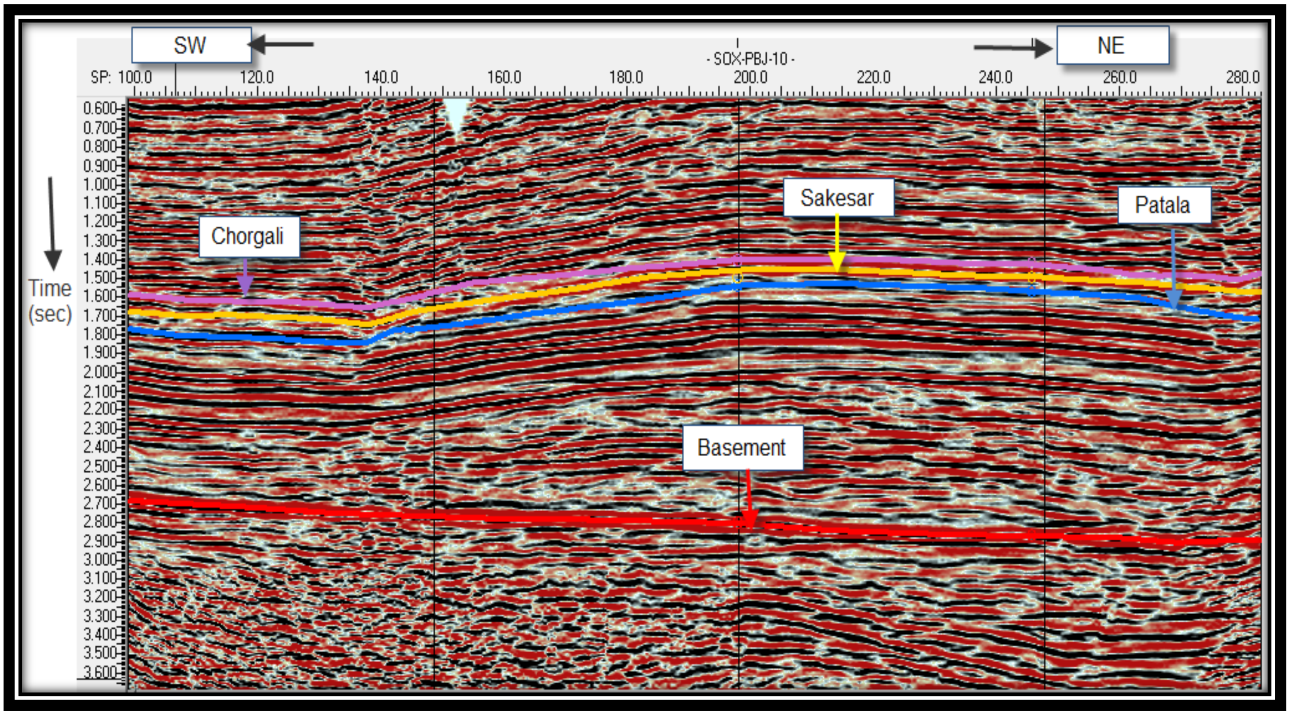


Figure 3.8 Interpreted Time Section of SOX-PBJ-10

3.9 Fault polygon:

The fault in seismic section is called Fault Segment and the fault on map view is called Fault Polygon (Sroor, 2010). A fault polygon represents the lateral extent of dip faults or strike faults having same trend. contouring without fault polygon not represent the clear picture. I construct the fault polygon at chorgali level, patala level and khewra level. Because chorgali is acting as reservoir and patala act as a source.

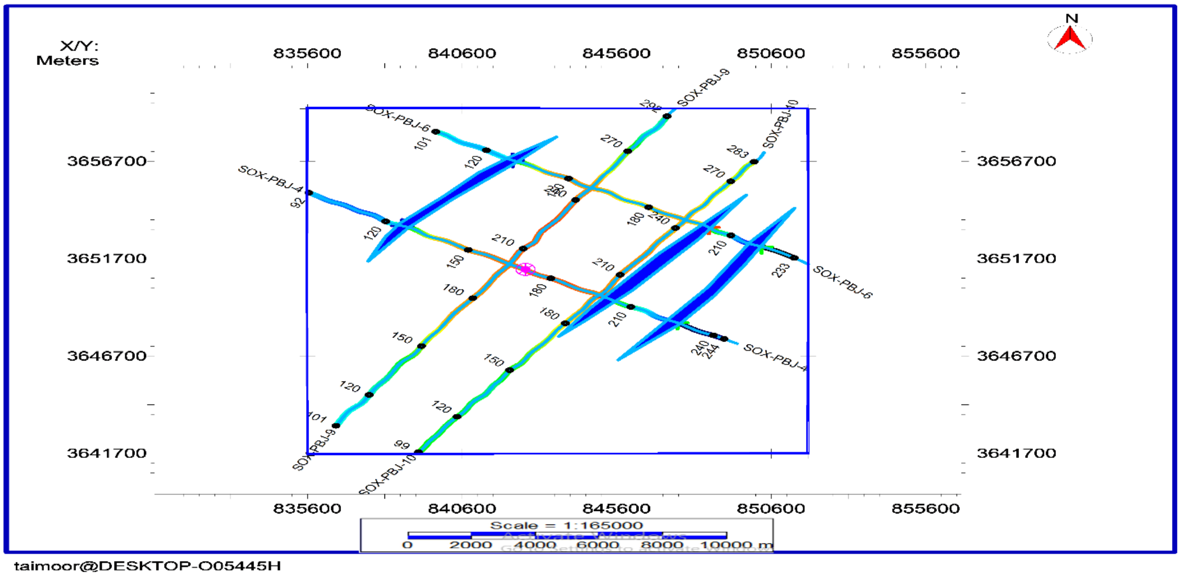


Figure 3.9 Fault Polygon Orientation on Base map

3.10 Contour Maps:

Interpretation result of seismic data is typically presented in the form of contour maps of time and depth. Mapping is an essential part of the interpretation of the seismic data on which entire operation depend upon .The contours are generally the lines which join the point of the equal depth and time (Coffeen, 1986). Space of the contour lines is a degree of the slope steepness i.e. nearer the spacing, steeper the slope. Contour maps tell the gradient of the formation, structural style of the formation, faulting, folding etc.

<u>Time Contour map of Chorgali</u>:

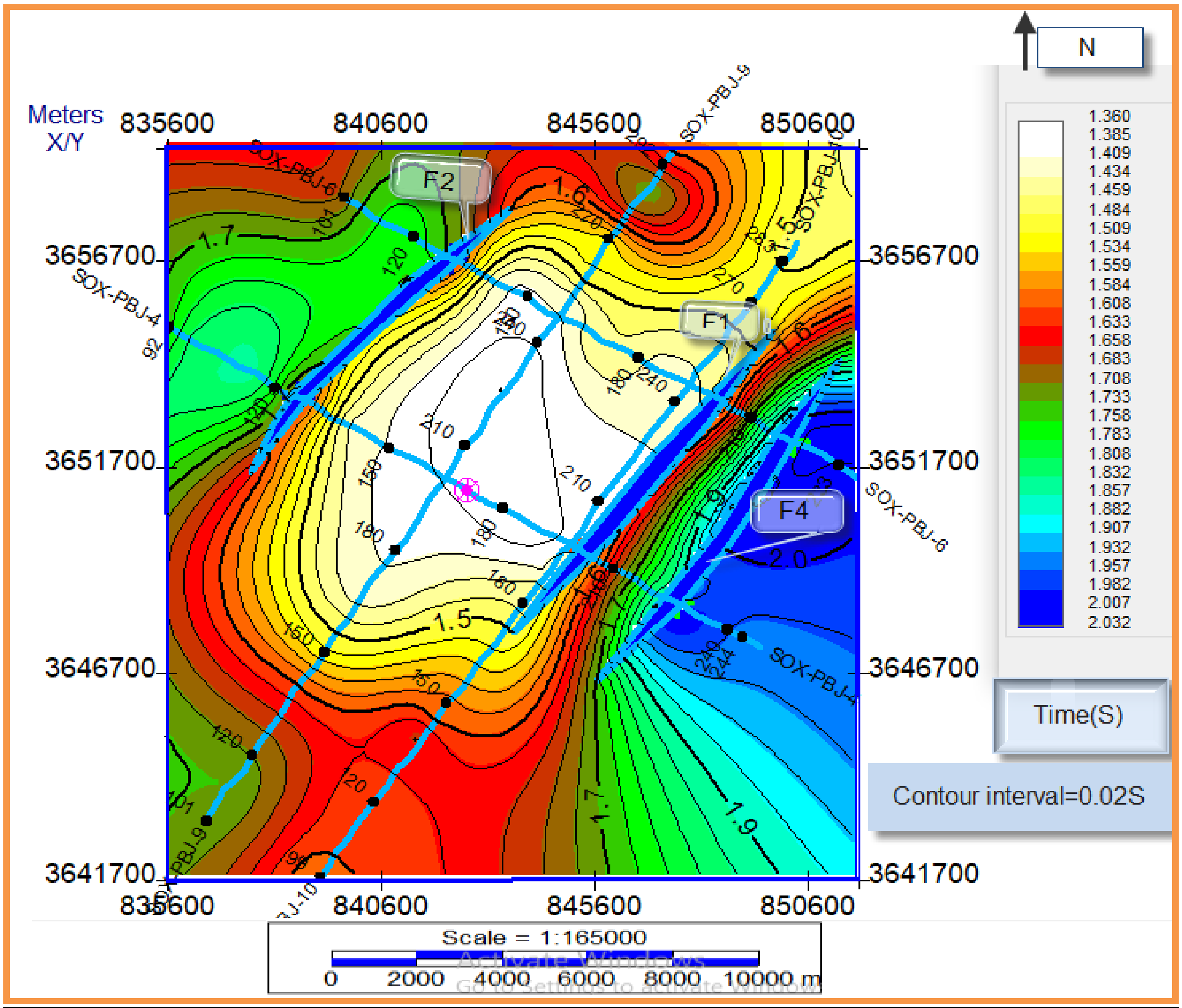


Figure 3.10: Time Contour Map of Chorgali Formation

Chorgali is primary zone of interest, it is oil and gas producing and is composed of limestone with some shale content. Two way travel time map of chorgali formation is shown in figure 3.10.It depicts the NE-SW oriented Balkassar anticline on the basis of time variation ranges from 1.360

to 2.0 seconds. Central Porton of contour map bounded by F1 and F2 represented by white colour whose time value ranges from 1.36 to 1.434 seconds are shallowest portion while deeper part is represented by blue colour with time value ranges from 1.9 to 2.0 second. Chorgali formation deepening towards NW-SE where time value increases while formation is shallower towards NE-SW direction. Reverse fault F1 and F2 are dipping towards each other that completely describe the anticlinal feature SO, our possible lead area can be mark at the peak point showing by white color(1.36-1.434).

Time Contour map of Sakesar:

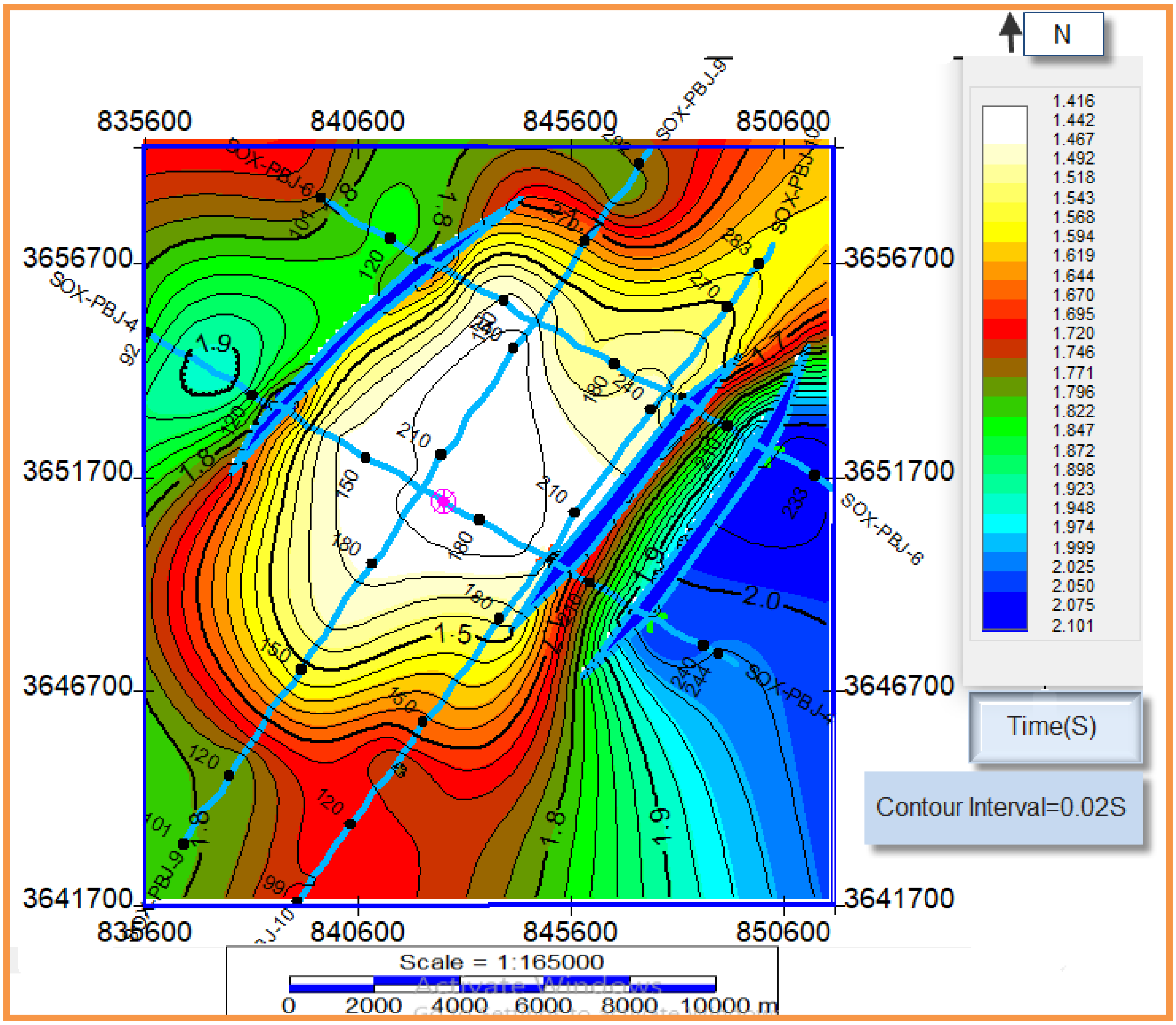


Figure 3.11 Time Contour Map of Sakesar Formation

Second formation used for the structural modeling of Balkassar Anticine is Sakesar formation lying below the chorgali, act as a reservoir. Time contour map of Sakesar formation depicts the

the same structural style as shown by chorgali formation. Time value ranges from 1.416 to 2.1 seconds. Blue color shows the deepest portion while white color shows the shallowest portion.

Time Contour map of Patala:

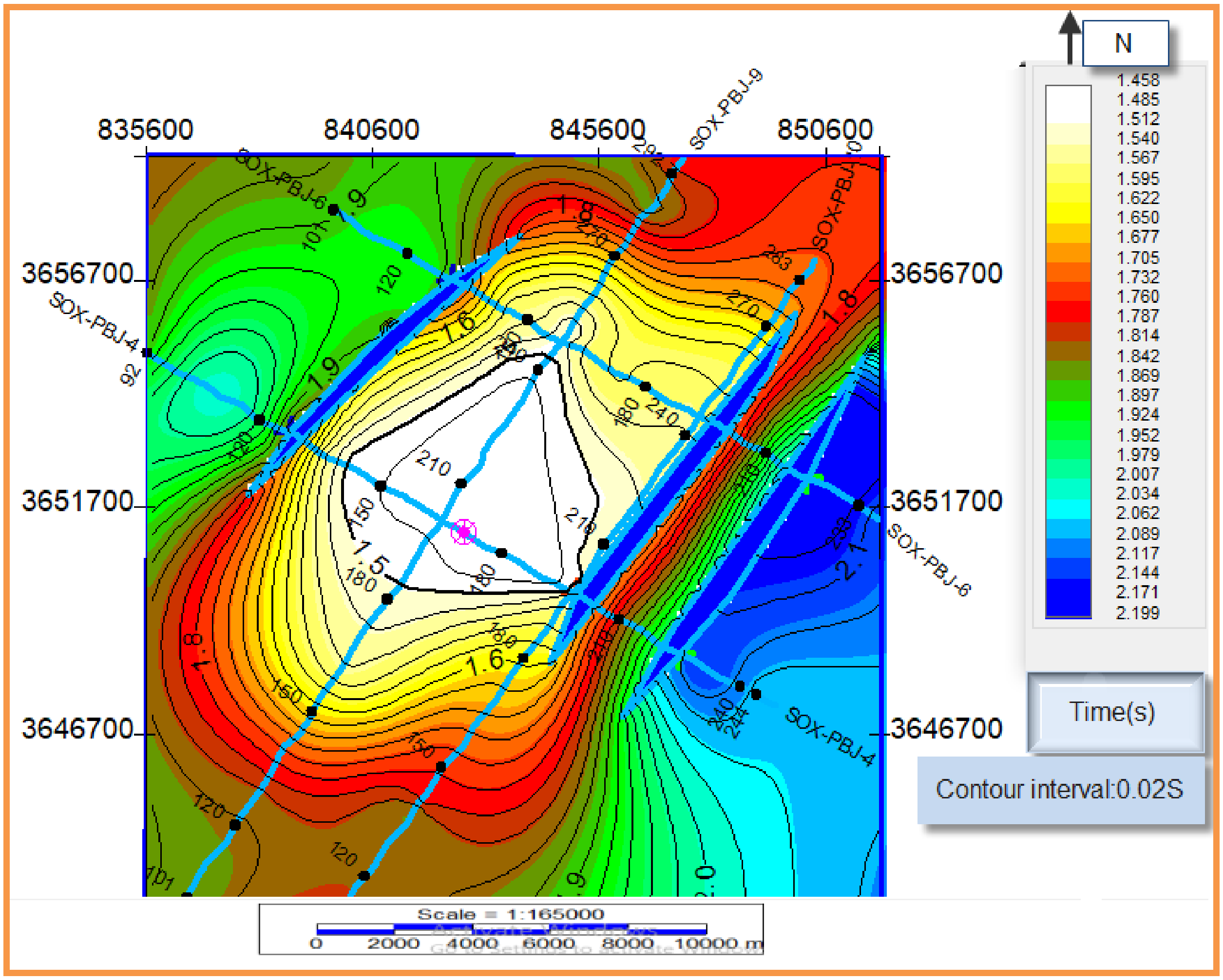


Figure 3.12 Time Contour Map of Patala Formation

Third formation used for the structural modeling of Balkassar Anticine is Patala formation, act as a source. Time contour map of Patala formation shows the anticlinal feature.Time value ranges from 1.45 to 2.19 seconds. Blue color shows the deepest portion(2.11 to 2.19 seconds) while white color shows the shallowest portion(1.45 to 1.54 seconds)

Time Contour map of Basement:

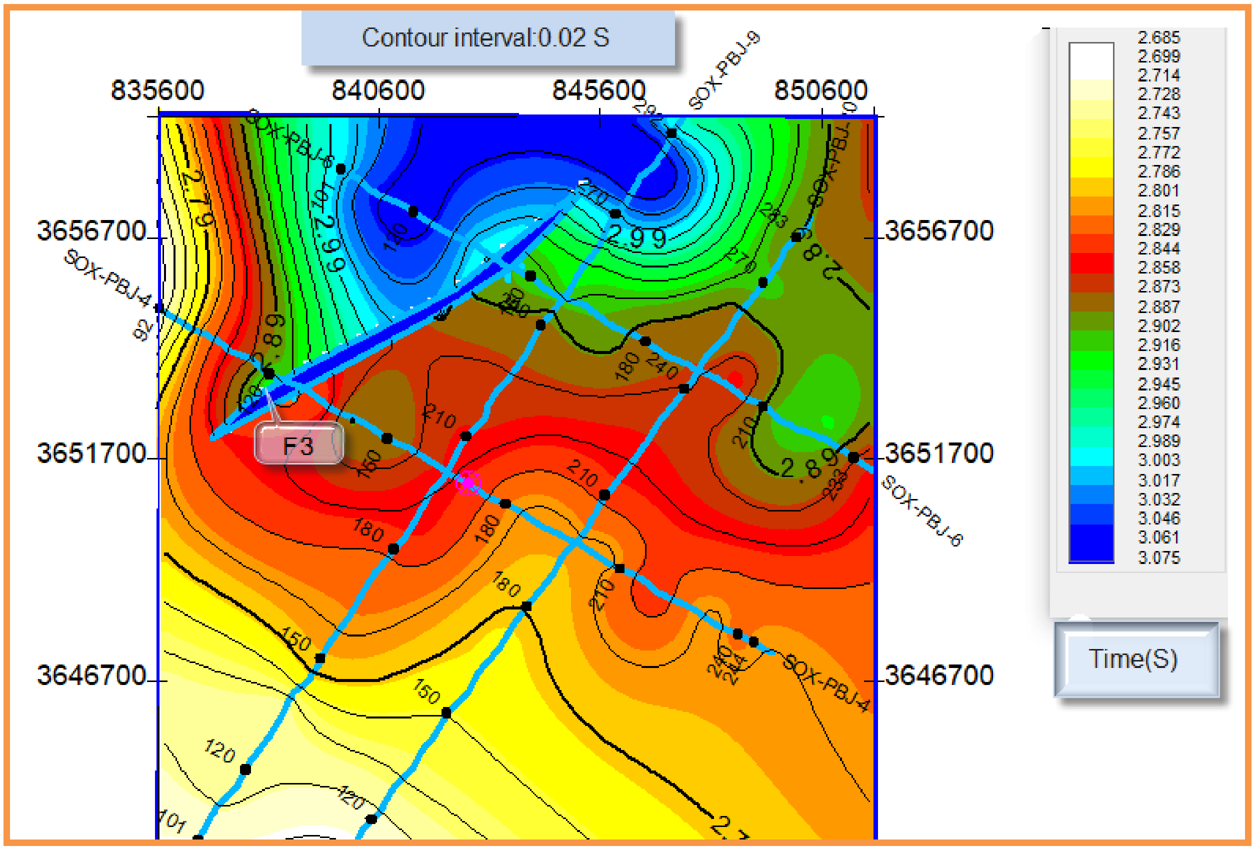


Figure 3.13 Time contour map of Basement

Time contour map of basement reveals normal faulting in basement .Along the fault F4 blue color (3.017 to 3.075) s) on the one side shows the highest time value while red color (2.8-2.9s) on the opposite side shows the lowest time value.

I have generated a depth contour map at the level of Chorgali , Sakesar and Patala formation using dynamic depth conversion plugin in Kingdom software. Depth contour map of formations are generated by using velocities that are estimated from DT log (sonic).General formula used for depth conversion is

$$S=VT/2$$

Depth Contour map of Chorgali:

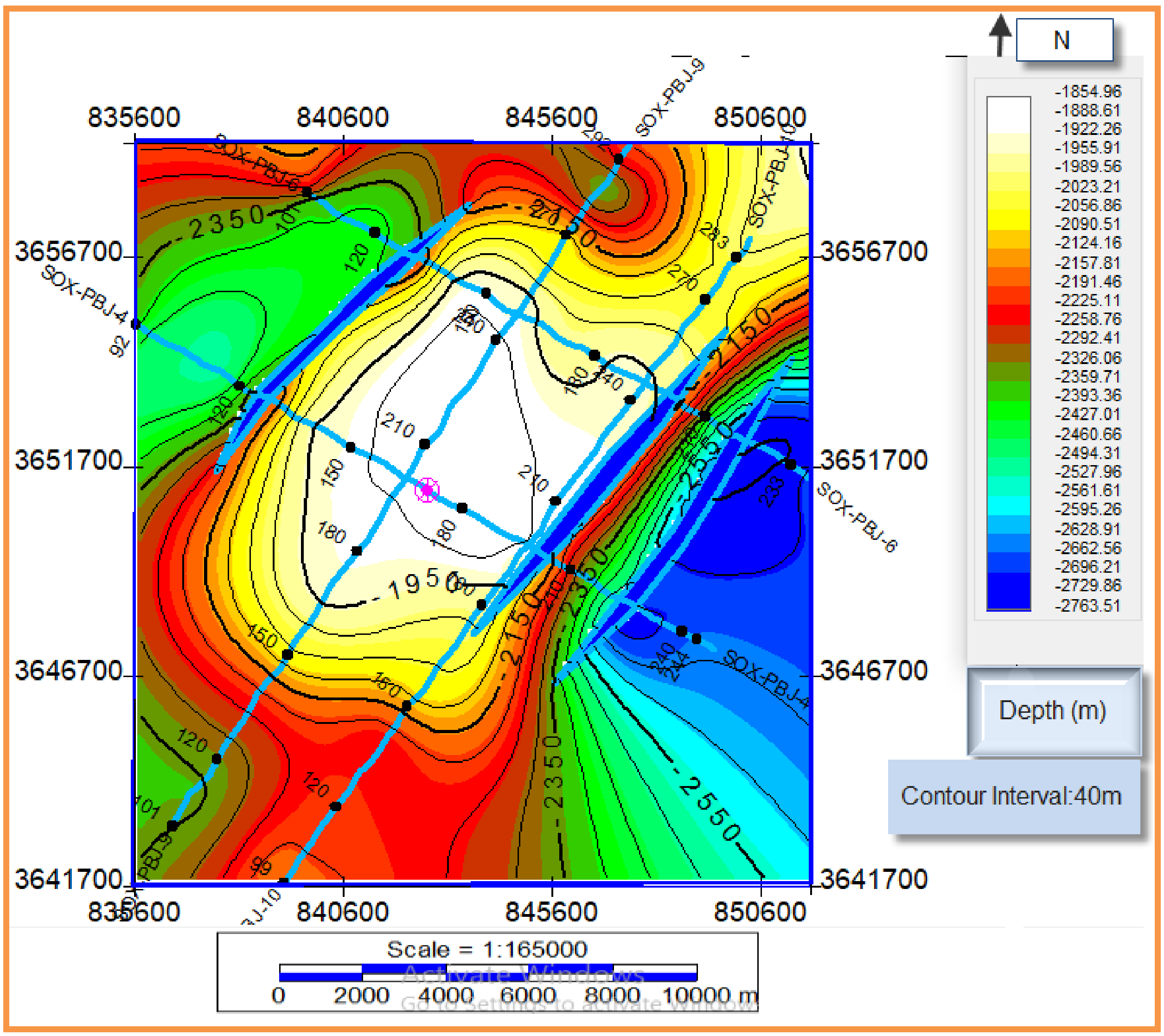


Figure 3.14 Depth contour map of chorgali

Above figure 3.14, shows depth contour map of Chorgali formation.Their structural variation are discussed through color bar and legends. White color shows the shallowest portion and dark blue present the deepest portion with contour value ranges from 1854 m to 2763 m. Color bar shows the depth with negative value that describe that our study area exsist below mean sea level. Shallowest portion bounded by F1 and F2 that completely indicate the presence of anticline “pop up” structure. It is clear from Fig that the chorgali formation is deepening NW-SE direction as the depth is increasing in this direction, while formation is shallower towards NE-SW because depth is decreasing in this direction.white color shows the crest point that may our possible lead area.

Depth Contour map of Sakesar:

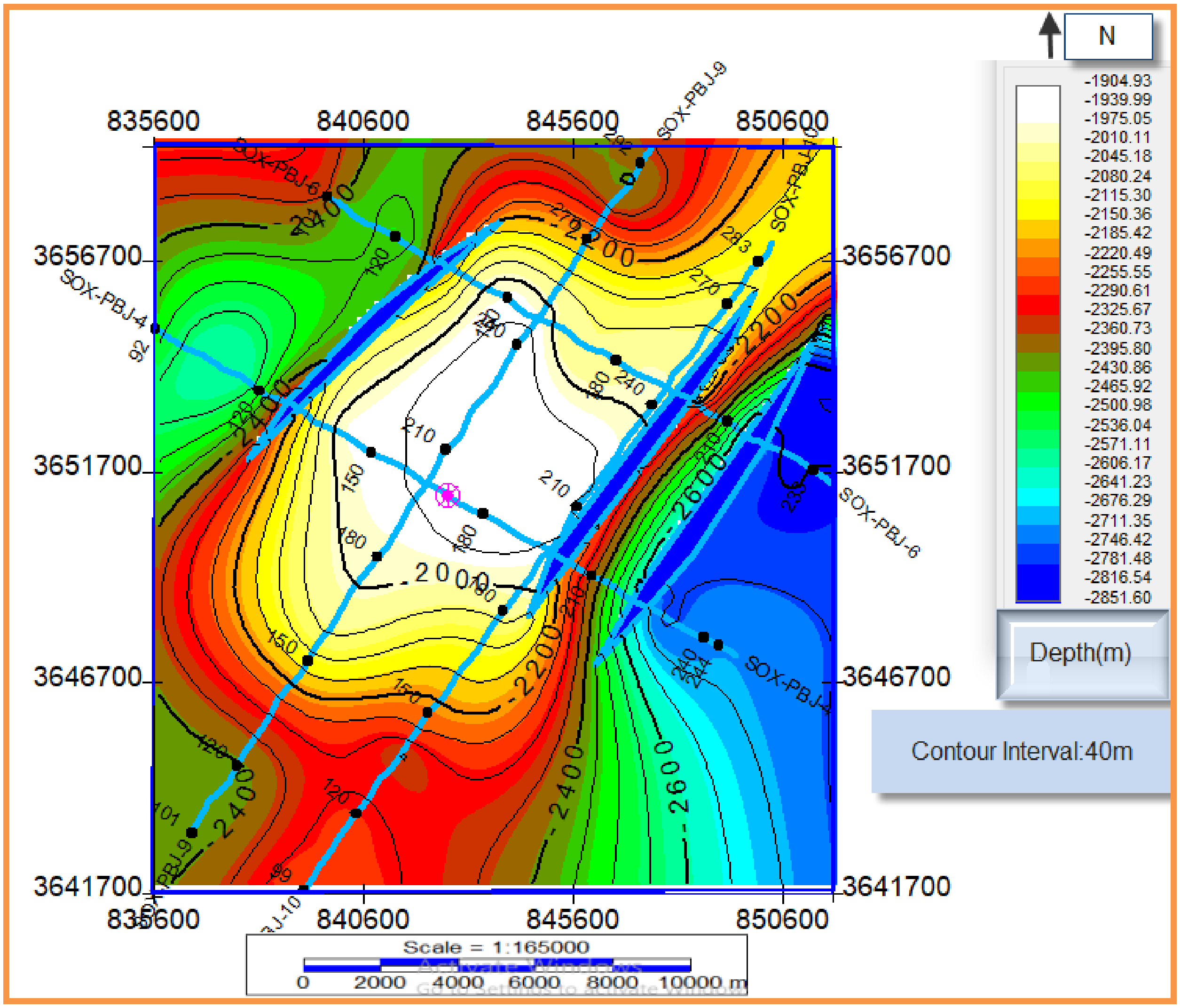


Figure 3.15 Depth contour map of Sakesar

Above figure 3.15 depicts that Sakesar have same structural style followed by chorgali formation with contour value ranges from 1904m to 2851m.Tectonics behaviour remain the same.

Depth Contour map of Patala:

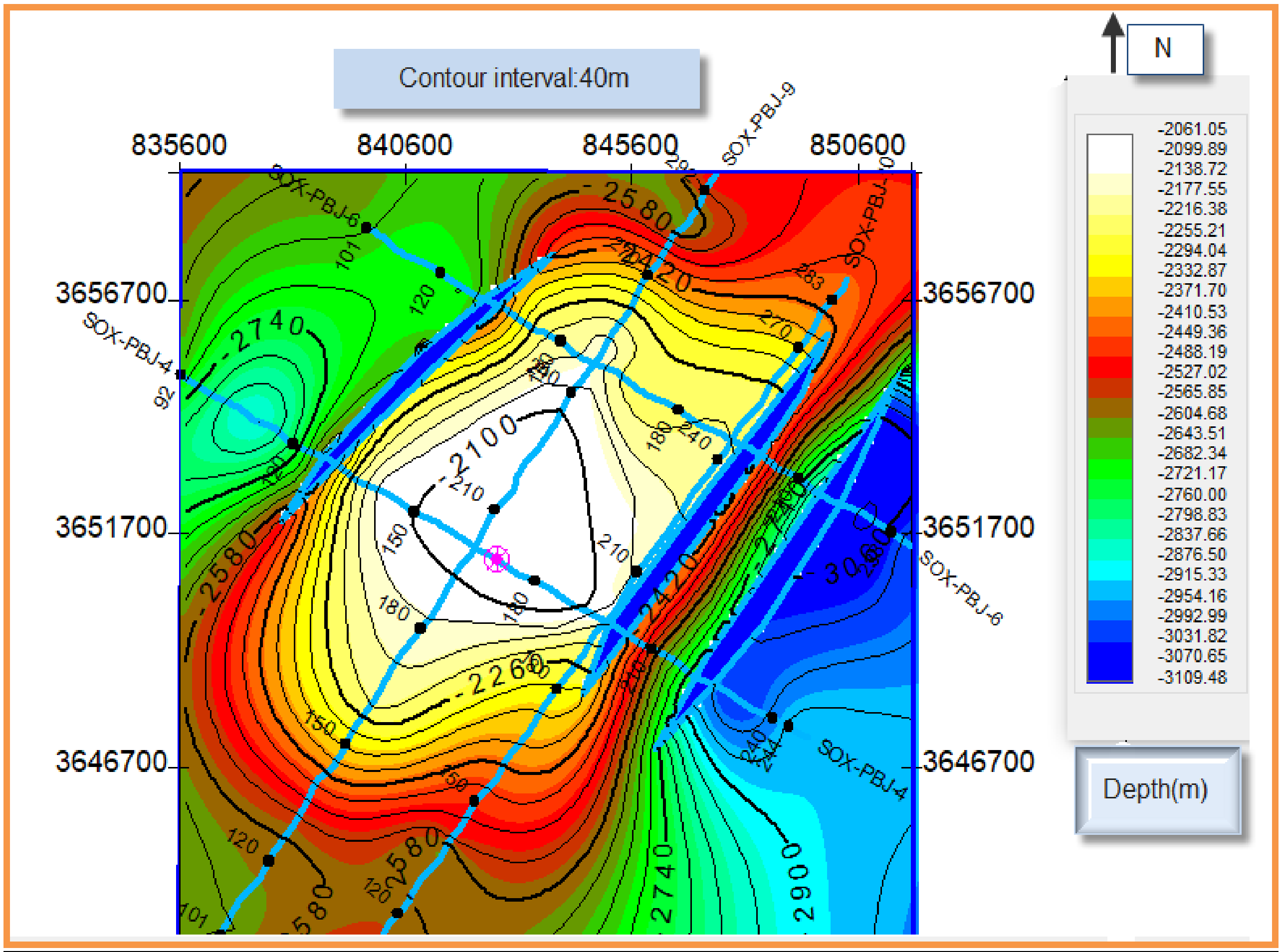


Figure 3.16 Depth contour map of Patala

Third formation for structural modeling of the subsurface of Balkassar area is Patala formation. Contour values of a depth map ranges from 2061m to3109m.white color shows the shallowst portion while blue color shows the deepest portion

3.11 Conclusion:

Following conclusion are drawn from above Time and Depth contour maps

- A perfect pop up structure and anticline is identified that is faulted at the limb
- Suitable for the Hydrocarbon Accumulation
- Murree and Kamlial act as seal
- Chorgali and Sakesar act as reservoirs
- Shales of Patala act as source

CH#4 PETROPHYSICS

4.1 Introduction:

Petrophysics is the study of the physical properties that describe the occurrence and behavior of rocks and fluids within the rocks. Petrophysics is one technique used for the reservoir characterization. This study helps in identification and quantification of fluid in a reservoir (Aamir et al., 2014). Reservoir characterization is the key step in oil and gas industry as it helps in defining the well and field potential so identify the zones within the reservoir which bears the hydrocarbons and can be recovered (Cosgrove et al., 1998).For reservoir characterization, density, neutron and resistivity measurement are made, from which we can quantify effective porosity, saturation of oil, gas or water and permeability. All kinds of logs, core data and production data are used in Petrophysics.Petrophysics is less concerned with seismic data, but more with well bore measurements. It gives porosity, shale volume, saturation of water, oil or gas, net pay, fluid contacts, permeability and reservoir zonation.

4.2 Data used for Petrophysical Analysis:

For reservoir characterization, petrophysical analysis of Balkassar area has been carried out. For this purpose, Balkassar OXY-01 has been used. The log curves of these bore hole includes; i.e. Spontaneous potential (SP) log, Gamma ray (GR), Sonic log (DT), Latro log deep (LLD), Latro log medium (LLM), Latro log shallow (LLS), Neutron log and Density log (RHOB) etc. Using Kingdom suit for petrophysical analysis, we have adopted procedure which flow is shown in figure below, we have calculated following parameters, Hydrocarbon saturation, Water saturation, Volume of shale and both Average and Effective Porosity. Basic scheme which has been followed for petrophysical well logging is shown in figure (4.1).

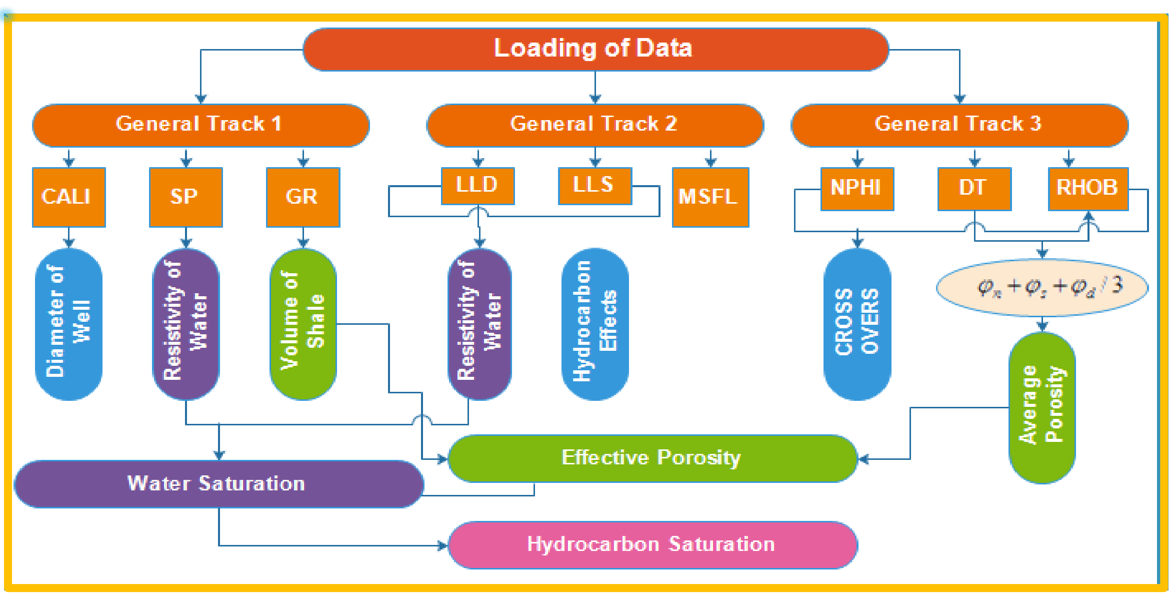
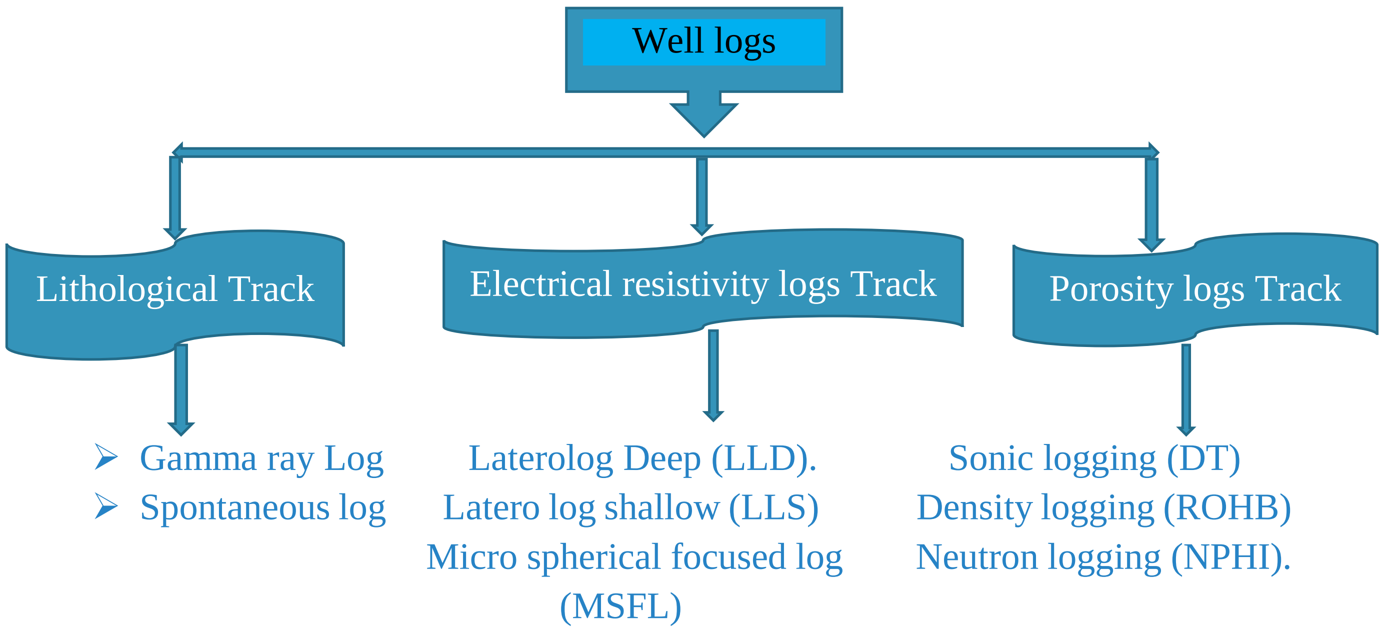


Figure 4.1: Flowchart of scheme used for Petrophysical Analysis

4.3 Classification of well logs:

To perform the petrophysical analysis by using Balkassar OXY-1 well logs data you must know about the characteristics of different logs run in a well.



Gamma ray (GR):

In 1953, Well Surveys Inc. technologically advanced the first practical device which could record the earth's natural radiation in well bore. Later on it was known as Gamma Ray Log. It measures the radiation of the combined elements of parent and daughter product, of the three main radioactive families: Uranium, Thorium and Potassium. It is used to identify lithology (shaliness) and to derive the shale volume of a formation.

Spontaneous Potential (SP) Logging:

The 'Spontaneous Potential' log record naturally occurring potential in the well bore. It has a single moveable electrode in bore hole and a reference electrode on surface, usually situated in the mud pit. The'Spontaneous Potential' curve is a record of the potential difference, which present between the surface electrode and the moving electrode in the bore hole. It is used to distinguish the permeable and non-permeable bed, calculate the volume of shale and detect the bed boundries.

Caliper Log (CALI):

Caliper log use to measure the borehole size. This log give us help to identify the cavity washouts and break outs. Hence this log is also called the quality check for other logs. Because if any where there is say wash out then in front of the wash out the porosity and resistivity log will not give the correct reading. Hence caliper log is very important in pertophysical logs.

MSFL:

Microspherically focused log measures the resistivity of the flushed zone (Rxo).

Laterolog Deep (LLD):

Latero log deep is used for the deep investigation of the quietly undisturbed (Uninvaded zone).This log is also used for saline muds also in case of fresh mud. This log is generally used for measuring the formation resistivity. LLD is a deep penetration than LLS.LLD is effected by borehole, adjacent formations and thin bed

Laterolog Shallow (LLS):

Laterolog shallow (LLS), used for shallow investigation of the transition zone / invaded zone. Because the depth of the investigation is smaller than the LLD

Density logs:

The density log is a continuous record of a formation's bulk density. This is the overall density of a rock including the density of minerals (solid matrix) and the volume of free fluid enclosed in the pores (porosity).

Neutron log (NPHI):

This is the type of porosity log which measure concentration of Hydrogen ions in the formation. Neutron is continuously emitted from chemical source in the tool of the neutron logging. When these neutron collide with nuclei in the formation and results in loss of some energy. Hydrogen atom has same mass as that of neutron, maximum loss of energy occurs when electron collides with hydrogen atoms.Hydrogen is an indication of the presence of the fluid in the formation pores,hece loss of energy is releated to the porosity of the formation.The neutron porosity is very low when the pores in the formation are filled with the gas. A high neutron count rate indicates low porosity, while low neutron count rate indicates high porosity.

Sonic log:

Sonic log is a porosity log that measures interval transit time of compressional sound waves.Sonic travel time is a function of porosity and formation Lithology (Asquith and Gibson, 2004). It displays travel time of P-waves versus depth. Sonic logs are typically recorded by pulling a tool on a Wireline up the wellbore. The tool emits a sound wave that travels from the source to the formation and back to a receiver.For porous rock the travel time increases and hence the larger deflection occurs on the log display and for denser and nonporous material the traveling velocity increases and hence the travel time decreases.

To calculate porosity from sonic log we must know formation matrix velocity. By Wyllie's formula

$$\varphi_{sonic} = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$$

Where : Δt_{log} is the interval transit time of formation
Δt_{ma} is the interval transit time of the matrix
Δt_f is the interval transit time of the fluid in well bore
Hilchie (1978) suggests the following empirical correction for hydrocarbons effect (for oil)

$$\varphi = \varphi_{sonic} \times 0.9$$

4.4 Calculation of Rock Properties of Chorgali and Sakesar:

4.4.1 Volume of Shale:

Volume of shale can be calculated through GR log and SP log but I calculated the volume of shale from GR log. There are two methods for calculation of GR.

Linear method:

we can calculate volume of shale as

$$IGR = \frac{GRlog - GRmin}{GRmax - Grmin}$$

Where $GRmax$ the maximum deflection of GR log (82 API)
$GRmin$ is the minimum deflection of GR log (19 API)
$GRlog$ is the average GR deflection of the formation
We have different GR models to calculate volume of shale

Non-Linear method:

<u>1-Steiber equation</u> (1970)

$$V_{Sh} = \frac{I_{GR}}{3 - 2I_{GR}}$$

<u>2-Clavier Equation</u>**:**

$$Vsh = 1.7 - \sqrt{3.38 - (IGR + 0.7)^2}$$

<u>3-Lorinove equation:</u>

Lorinove gave two different equations in 1969 for tertiary or unconsolidated rocks and for older or consolidated rocks. (Saputra et al,2008).

$$V_{Sh} = 0.31(2^{2\times I_{GR}} - 1) \quad \text{(For older rock)}$$
$$V_{Sh} = 0.083 \times (2^{3.7\times I_{GR}} - 1) \quad \text{(For tertiary rock)}$$

We are interested to calculate the less volume of shale so the best approximation are given by stieber method.

4.4.2 Porosity calculation:

Porosity is the ratio of volume of voids to total volume of rock. Porosity is calculated for different zones of interest by using sonic log, neutron log, density log.On the basis of sonic,density and neutron log we calculate the toatal and effective porosity.

$$\text{Porosity} = \frac{PORE\ VOLUME}{TOTAL\ BULK\ VOLUME}$$

Porosity
- **Density porosity**
- **Neutron porosity**
- **Total porosity**
- **Effective porosity**

<u>Density Porosity (PHID):</u>

Porosity that is calculated by using the density log is called Density porosity. Density porosity has been calculated with the help of following formula.

$$\varphi d = \frac{\rho_m - \rho_{log}}{\rho_m - \rho_f}$$

Where
ρ_f is the fluid density
ρ_m is the matrix density
ρ_{log} is the log density
φd is the density porosity.
For limestone matrix density is 2.71g/cm3 and density of fluid is 1g/cm3.

<u>Neutron Porosity (NPHI):</u>

Neutron logs give directly the porosity values on the log track in a clean formation. It is different from the density and sonic tools because it can read extremely low porosity within a formation.

<u>Total Porosity (PHIT):</u>

It is average of the neutron,density and sonic porosity as given below

$$PHIT = \frac{\text{NPHI+PHID+}\Phi\text{s}}{3}$$

<u>Effective porosity:</u>

The interconnected pore volume or void space in a rock that contributes to fluid flow or permeability in a reservoir. Effective porosity excludes isolated pores and pore volume occupied by water adsorbed on clay minerals or other grains. Effective porosity is less than total porosity. Log of effective porosity were acquired using Density porosity, Neutron porosity and sonic logs.

$$PHIE = \frac{(PHID+NPHI+\Phi\text{s})\times(1-VSH)}{3}$$

Effective Porosity for the the chorgali Formation ranges from 13-15% and for the Sakesar formation ranges from 3-5%.

4.4.3 Water Saturation:

Water saturation is the percentage of pore volume in rock that is occupied by water of Formation. If it is not confirmed that pores in the Formation are filled by hydrocarbons, it is assumed that these are filled with water. To determine the water and hydrocarbon saturation is one of the basic goals of well logging. To calculate saturation of water in the Formation, a mathematical equation was developed by Archie shown below. All the parameters of Archie equation can be calculated from resistivity and spontaneous potential logs.

There are different models of determination of water saturation but we use Archie's model for the calculation of water saturation. We have a well (OXY-01) with many logs data. Archie equation is used to determine the water saturation from well logs.

$$Sw = (\frac{ARw}{\varphi^M Rt})^{\frac{1}{N}}$$

Gus Archie gives this equation in 1942 which relates the water saturation with the porosity and resistivity of formation.

Where

S_w=Water saturation=?

R_W= Formation Water Resistivity
A = tortuosity factor
R_t = resistivity for reservoir rock= ILD (KAMGANG, 2013)
M= cementation exponent=2 (KAMGANG, 2013)
N=saturation exponent=2

Calculation Of Rw:

Resistivity of water (Rw) is calculated after performing a series of calculations (Asquith and Gibson, 2004):

1) Note down values of surface temperature (ST), resistivity of mud filtrate (Rmf1) and maximum temperature (BHT).

2) Calculate Static Spontaneous Potential (SSP) using SP log from the relation (Rider, 1996).

$$SSP = SP(clean) - SP(shale) \quad .$$

3) Calculate Formation Temperature from the relation (Rider, 1996).

$$FT = ST + \frac{(BHT - ST)}{(TD)}\ (FD) \quad .$$

4) Calculate resistivity of mud filtrate from the relation,

$$R_{mf2} = R_{mf1} \times \left(\frac{ST+6.77}{FT+6.77}\right) \quad .$$

5) Calculate resistivity of mud equivalent (Rmfeq) from the relation or from schlumberger charts.

$$R_{mfeq} = 0.85 \times R_{mf2} \qquad .$$

6) Once the value of Rmfeq is derived, now calculate resistivity of water equivalent Rweq against Rmfeq at SSP value and BHT from S.P chart (Schlumberger chart) shown in Appendix A. Now the resistivity of water (Rw) is calculated against Rweq and FT by SP chart method (Appendix B).

For chorgali Rw is 0.042Ωm and Sakesar is 0.049Ωm

7) Calculate water saturation using Archie Water Saturation equation (Archie, 1942),

$$Sw(\%) = (A \times Rw/RT \times \emptyset^{M})^{\frac{1}{N}} \quad .$$

8) Now calculate hydrocarbon saturation using the relation,

$$S_h(\%) = 100 - S_w\ (\%)$$

4.4.4 Saturation of Hydrocarbon:

Water saturation is used to find out the hydrocarbon saturation. As we know that the sum of the water saturation and hydrocarbon saturation is always equal to 1 because both are fraction of the water or hydrocarbon in the total volume of the pore spaces.

Shc = 1-Sw

4.5 Well log interpretation of Balkassar OXY-1 :

In Balkassar OXY-1 well the reservoir mainly consist of limy shale and Limestone in Chorgali and Sakesar formation. Depth of Chorgali ranges from 2421m to 2467m, while Depth of Sakesar ranges from 2467m to 2602m. Petrophysical interpretation was done for both formations. From Petrophysical analysis volume of shale, water saturation, Total porosity, Effective porosity and hydrocarbon saturation has been calculated.

Formations	Volume of Shale (%)	Porosity		Water saturation (%)	Hydrocarbon Saturation (%)
		Total (%)	Effective (%)		
Chorgali	15	13	11	70	30
Sakesar	31	2.5	1.8	85	15

Table 4.1: Petrophysical result of Chorgali and Sakesar

4.6 Petrophysical Analysis of chorgali Formation:

The payable zone of chorgali has been marked at a depth of 2445m to 2452 m having thickness of of 7m.Petrophysical properties of this zone are as under:

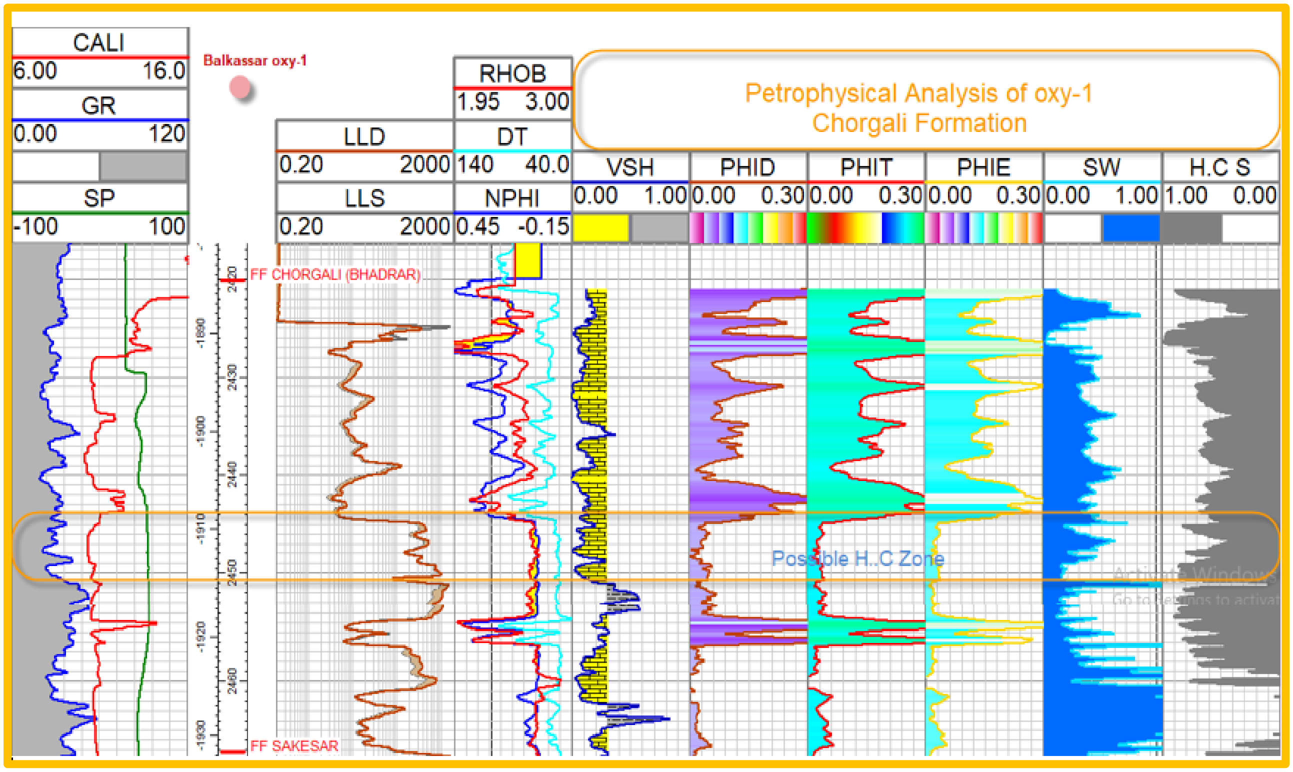


Figure 4.2:Logs profiles with a zone showing some potential

Properties	AverageValues (%)
Volume of Shale	9
Effective Porosity	4
Hydrocarbon saturation	69
Water saturation	31

Table 4.2: Petrophysical result of zone in Chorgali

Chorgali shows the reservoir potential but porosity of reservoir indicate that it is a tight reservoir. Limestone with interclation of Shale detected by GR log.Overall the calliper response along the borehole in chorgali is disturbed that is due to lithology washout. Bad Borehole zone in chorgali formation ranges from 2420m to 2440m that zone indicate the high porosity value but actually it is a low porosity. sonic and Density log are most effected by the bad borehole effect beacause their pads are attached to the wall of borehole so their reading leads to the wrong interpretation of reservoir. Zone in chorgali formation that shows some potential ranges from 2445m to 2452m in which GR log shows low value,LLD and LLS Shows high value ,crossover found between NPHI and RHOB in a interested zone. Hydrocarbon saturation are more than 50%.

4.7 Petrophysical Analysis of Sakesar Formation:

Three payable zone of sakesar formation has been marked at depth 2475m to 2483m having a thickness of 8 m. second zone ranges from 2490m to 2500m and third zone ranges from 2550 to 2560m havig thickness of 10m.

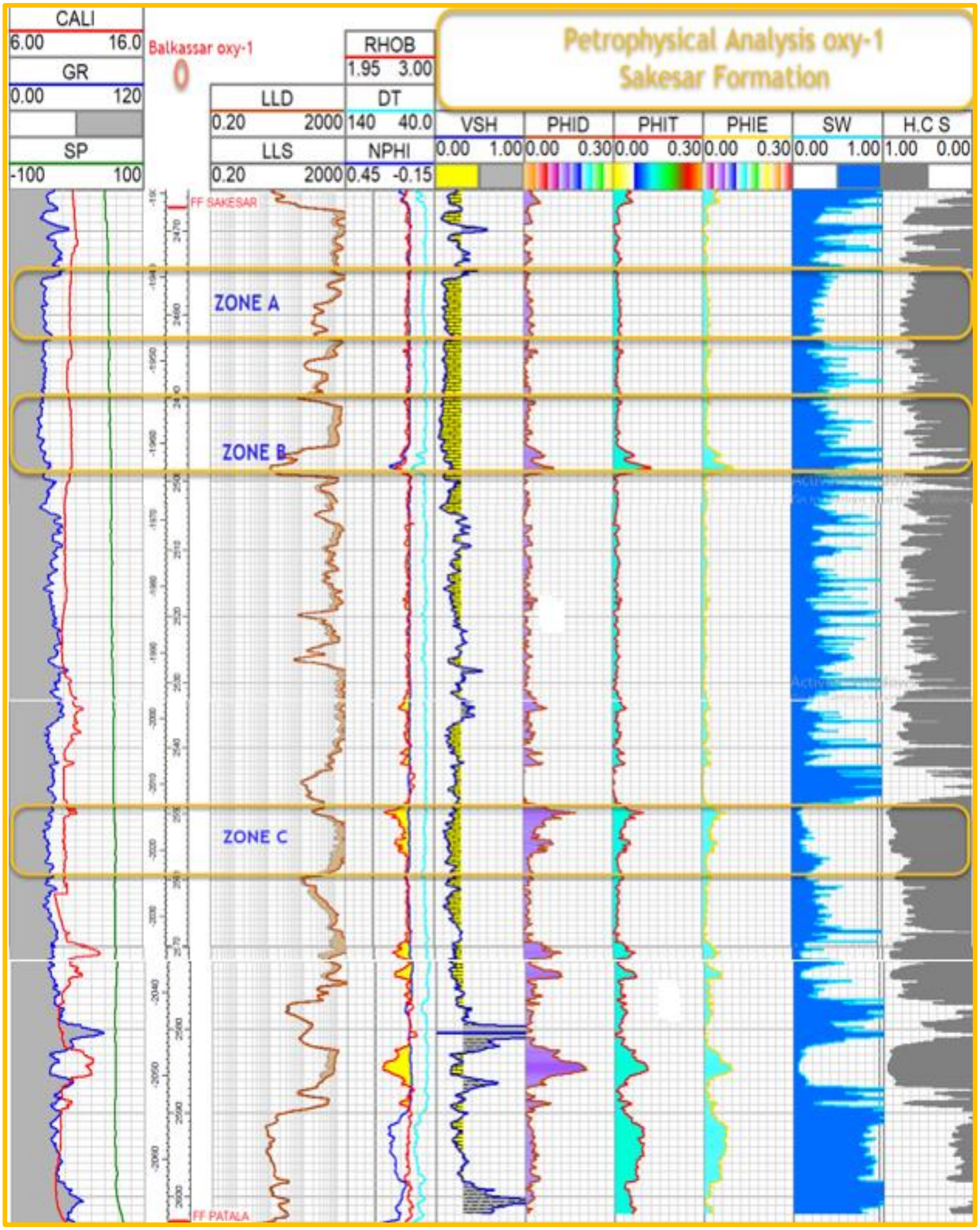


Figure 4.3 Sakesar Logs profiles With a zone showing some potential

Average values (%)	Volume of shale	Effective Porosity	Hydrocarbon saturation	Water saturation
Zone A	14	1.5	71	29
Zone B	11	2	55	45
Zone C	16	3	70	30

Table 4.3: Petrophysical result of marked zone in Sakesar

Sakesar formation also shows reservoir potential but porosity is less than 0.05 that shows that it is highly tight reservoir as compared to chorgali formation.Calliper log is not much disturbed in sakesar that's why logs response are helpful for true interpretation. Hydrocarbon are found in the form of patches so, I marked the three zone of interest that may be our payable hydrocarbon bearing zone at depth of 2475 to 2483m (Zone A),2490 to 2500m (Zone B),2550m to 2560m(Zone C) which are confirmed by the calculation of petrophysical properties of each marked zone. Hydrocarbon saturation are more than 50% in the Probable Zone of interest.

Reliable method for estimating the porosities in case of washout is a crossplot between neutron and density porosity.

CH#5 FACIES AND ROCK PHYSICS MODELING

5.1 Facies Analysis:

Geologically facies is a rock body which having some specific characteristics which distinguish it from the other (Ravia et al., 2010).The identification of a bed's lithology is basic to all reservoir characterization because the physical and chemical properties of the rock that holds hydrocarbon and/or water affect the response of every tool used to measure formation properties. Understanding reservoir lithology is the basic from which all other Petrophysical calculations are made. To make accurate Petrophysical calculations of porosity, water saturation (Sw), and permeability, the various lithologies of the reservoir interval must be identified and their implications understood. Lithology means "the composition or type of rock such as sandstone or limestone. There is a material correlation between the behaviour of well logs and the lithologic and depositional facies of penetrated formations, since modern logs are sensitive to factors that vary with the makeup of those formations, (Saggaf and Nebrija, 2000). These facies are releated to the certain depositional environment. Basically the depositional environment is specific type of place where the facies are deposited. Such as the Glaciers. Lakes, Abyssal plain, Sea bottom. Stream, Delta etc. The different types of the sedimentary environment are showen in the below figure 5.1.

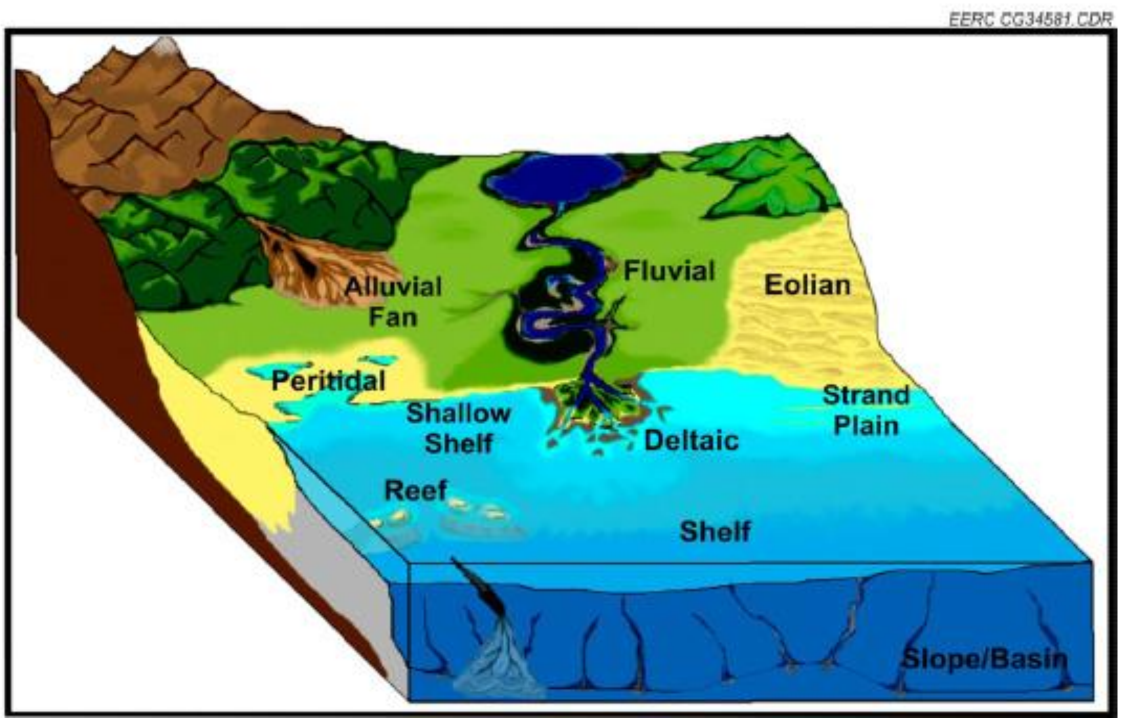


Figure 5.1:Diagram of major depositional environments, (Rais etal, 2012)

5.2 Crossplot between LLD,RHOB and GR:

Crossplot is prepared by using a Kingdom software between LLD and RHOB and GR is used as a third indicator for lithology discrimination.

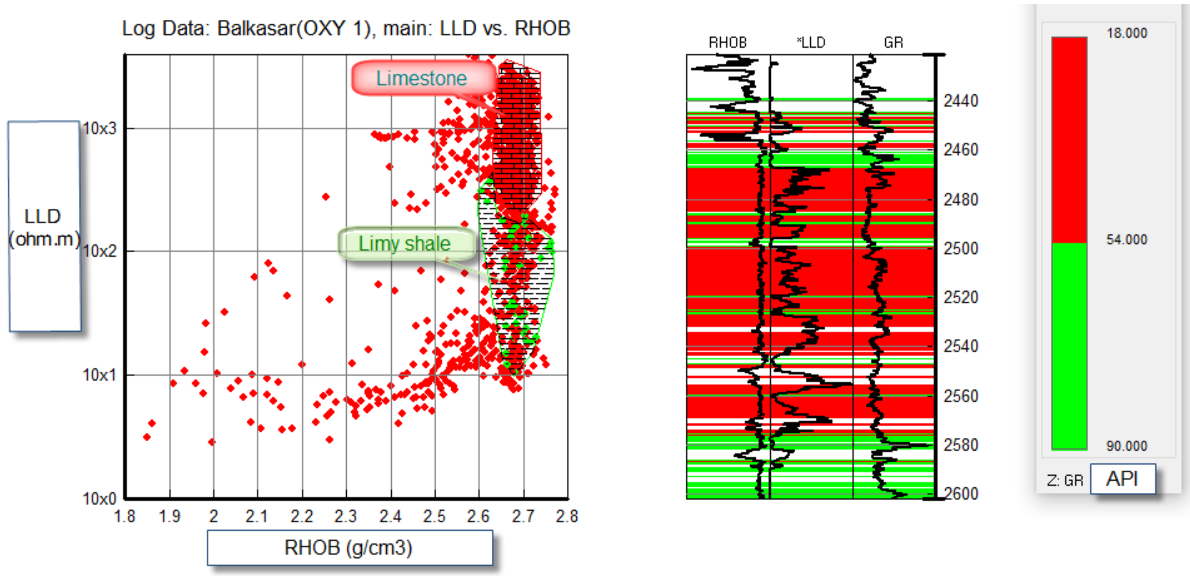


Figure 5.2 Crossplot of LLD and RHOB of chorgali and Sakesar

Result:

- High resistivity values corresponding to low gamma rays value as compare to sandstone indicate limestone.so, the polygon that is designed at the top of cross plot indicate limestone by showing high resistivity values associated with low GR values(Generally radioactivity of limestone ranges from 10-40 API)
- High gamma ray values associated with low resistivity values indicate shale but in chorgali and sakesar formation we donot have a pure shale,found a calcareous shale or limy shale (major content is calcite) whose density ranges from 2.6 to 2.7g/cm3.Polygon that is designed at the bottom of crossplot shows the limy shale.

5.3 Crossplot between DT,NPHI and GR:

Crossplot is designed between DT and NPHI and GR is used as a refrence. we found the direct relation between DT and NPHI.DT value will be high in loose or Porous lithology while in case of compact or hard rock it shows low value. Neutron log measure the concentration of hydrogen atoms that directly indicate the porous lithology.

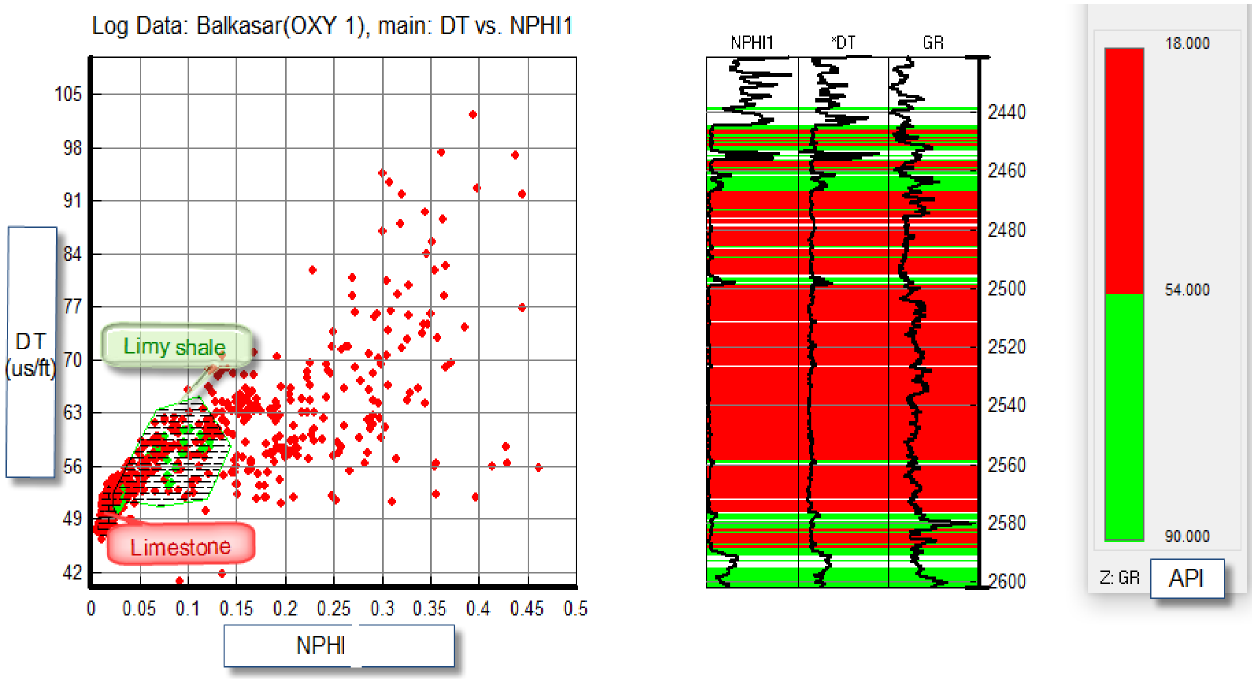


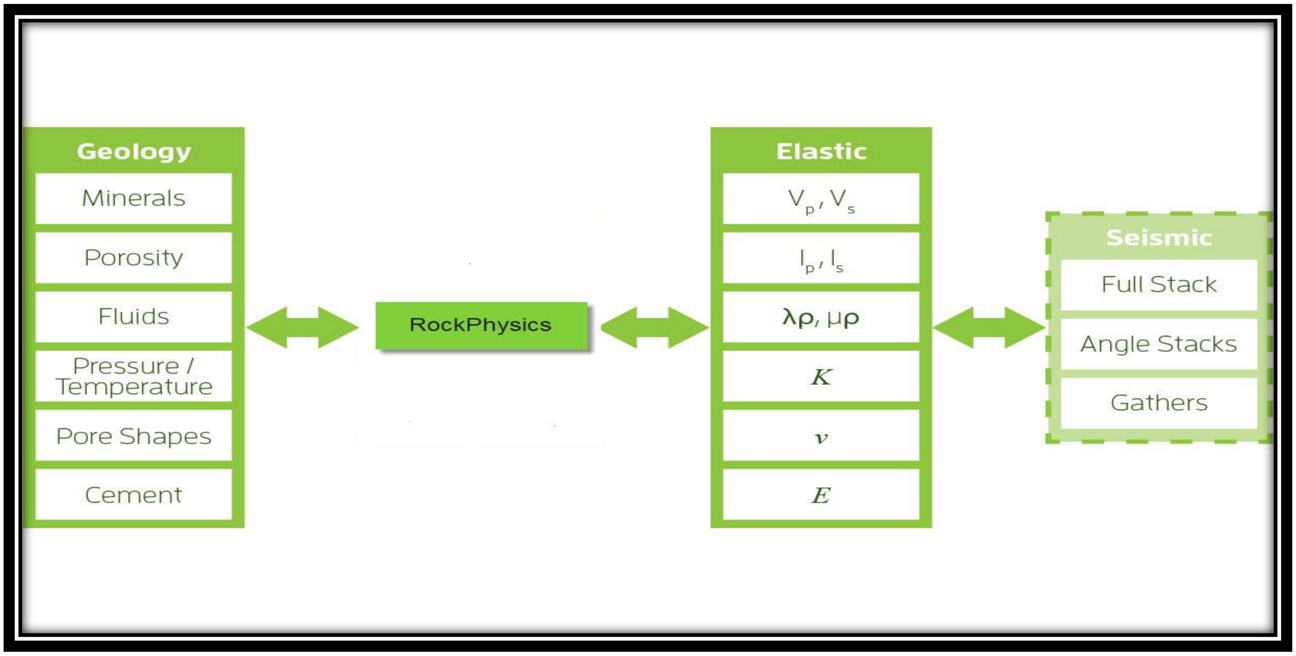
Figure 5.3: Crossplot of DT and NPHI of chorgali and Sakesar

Result:

- Low value of DT associated with low value of GR indicate limestone. Polygon that is designed around a cluster point shows the limestone.we categorized it as a limestone because limestone also show itself radioactive behavior and their general value of GR ranges from 10-40 API. DT value of limestone ranges from 47 us/ft-52 us/ft in our study that matches with the standard range of transient time for limestone.
- Comparatively, Higher value of DT and higher GR values indicate shale but in our reservoir we donot have a pure shale, found a limy shale(calcareous shale or shaly limestone) that shows comparatively low value of DT,NPHI,GR as compare to Pure shale. Second Polygon shows the limy hale.

5.4 Rock Physics:

Rock physics is a powerful tool for reservoir characterization. Rock physics relate porosity, mineralogy (shale content), saturation and pore fluid properties to the elastic rock properties (elastic-wave velocity and impedance) give the connection between flow simulation and synthetic seismic imaging. It is a bridge between seismic and well log data, and reduce the failure risk in hydrocarbons exploration.So,Rock Physics aims to establish P-wave velocity (Vp), S-wave velocity (Vs), density, and their relationships to elastic moduli κ (bulk modulus) and μ (rigidity Modulus), porosity, pore fluid, temperature, pressure, etc. for given lithologies and fluid types.



5.5 Elastic Rock Properties:

P-wave velocity:

From DT log, which has trainset time in μs/ft, we have calculated P-wave velocity in m/s using formula V=1/DT.

$$Vp=1 \times 1000000/\text{DT}\times 3.28 \text{ (m/s)}$$

S-wave velocity:

S- wave velocity in m/s has been calculated from P-wave velocity using formula.Castagna suggests a different formulas for Vs depend upon the lithology but it is not reliable for reservoir characterization. I use the formula given by Castagna in 1993 for limestone.

$$Vs = (0.583 \times Vp) - 0.078 \text{(m/s)}$$

Density

Density is a major property of the rock which describes the amount of solid part of the rock body per unit volume. Simply mass per unit volume is called density. Density is computed from velocity by equation.

$$\rho = 0.31 * (Vp)^{0.25}$$ (Castagna etal, 1985)

We already have the density log (RHOB) in the well data of Balkassar oxy-0`1.

Shear Modulus(μ):

The ratio of shear stress to the shear strain (angle of deformation) is termed as shear modulus. It signifies with the deformation of a solid when it experiences a force parallel to one of its surfaces while its opposite face experiences an opposing force such as friction. Mathematically it can be calculated by using relation. Shear modulus will be zero for fluid.

$$\mu = \rho * Vs^2$$ (Castagna etal, 1985)

Standard value for a limestone is 24GPa.

Bulk Modulus(k):

The bulk modulus (k) of a rock can be defined as the measures of the resistance of rock to uniform compression. It is the ratio of volumetric stress to volumetric strain. It describes the material's response to uniform pressure.Bulk modulus is only meaningful for the the presence of hydrocarbon because it depend upon the vp and density and both factors are decreasing when rock having a fluid.

$$K = (Vp^2 \times \rho) - 4/3\mu$$

Standard value for limestone is 65GPa.

Young's Modulus (E):

The tendency of body to deform along an axis when opposing or tensile stress are applied along that axis. Simply young's modulus can be defined as the ratio of tensile stress to the longitudinal strain.

$$E = 9 \times K \times \mu / 3K + \mu$$

Standard value for limestone is 15-55GPa

Vp/ Vs Ratio:

It is the ratio between the primary wave velocity to the secondary wave velocity and calculated simply by dividing by Vp by Vs.

Poisson ratio(σ):

The ratio of the transverse strain (relative contraction strain normal to the applied stress) to the longitudinal strain (relative extension strain in the direction of the applied stress).

$$\sigma = \text{Transverse Strain /Longitudinal Strain}$$

Standard value for a limestone is 0.18-0.33GPa.

Acoustic Impedance (Z):

Acoustic impedance is the product of primary wave velocity and density of the rock. Mathematically it can be written and calculated by the formula.

$$Z = Vp \times \rho$$

Shear Impedance:

Shear impedance is the product of the secondary wave velocity and density. Mathematically it can be written calculated by the formula

$$Is = Vs \times \rho$$

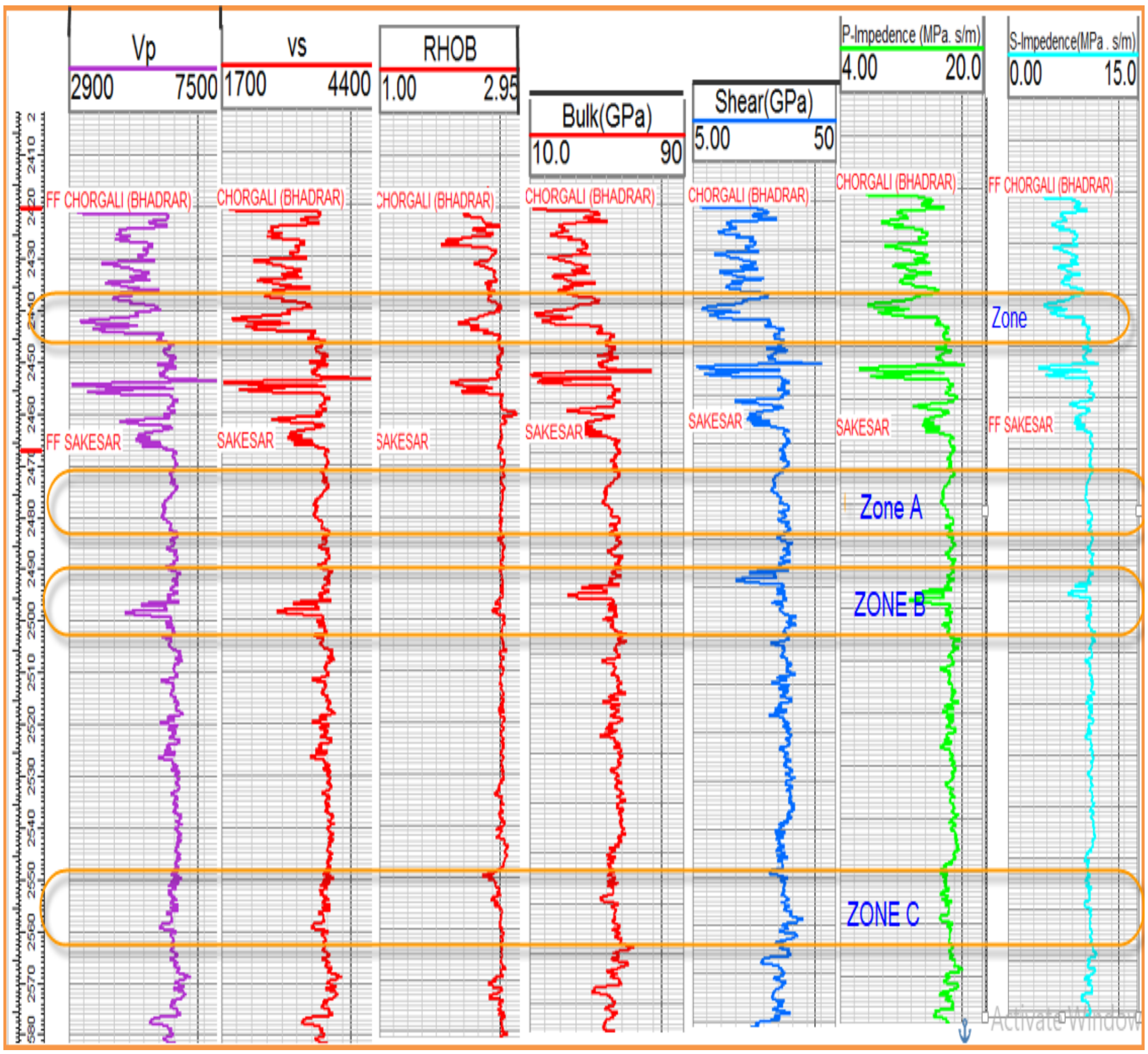


Figure 5.4: Combine response of elastic rock Properties in chorgali and sakesar

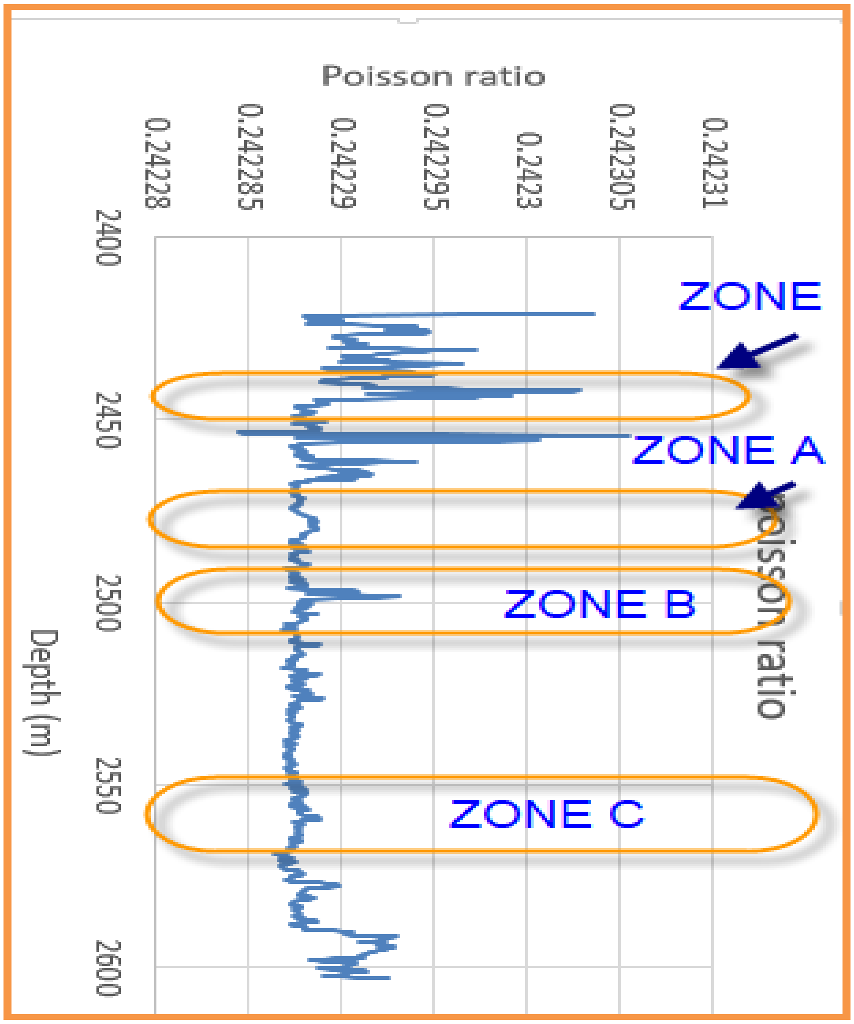


Figure 5.5: Curve Showing the values of Poisson ratio in Chorgali and Sakeasar

Result:

- Presence of Hydrocarbon in the payable zone causes to reduce the velocities and densities. Above figure 5.4 and 5.5 shows that in our interested zones (zone,zone A,zone B,zone C) these values are decreases.
- In case of shear modulus and bulk modulus also decreases due to presence of hydrocarbon as these all are the ratio of stress to strain which are directly related to each other.Figure 5.4, 5.5 shows that the in the marked zones shear modulus, bulk modulus are decreases which confirms the presence of hydrocarbon.
- Impedence is the product of density and velocity,as the velocity and density decreases due to presence of hydrocarbon so, it also causes to reduce the p- impedence and s-impedence.

CH#06 COLORED INVERSION

6.1 Introduction:

Colored inversion is a simple and robust technique for generating relative impedances from zero-phase seismic data, developed by Lancaster and Whitcombe (2000). The method is a convolution process: an operator is designed that performs a -90 degree phase rotation and spectral shaping to the seismic trace in order to generate relative impedance profiles. The spectral shaping matches the amplitude spectrum of the seismic to the earth impedance spectrum over the bandwidth of the inversion. The method does not require the generation of a background model, so is particularly appropriate in exploration settings. Depending on the attribute that has been inverted, the use of layer properties versus reflectivity can greatly assist the interpreter. Coloured inversion is a quick and robust way of generating layer properties from seismic. The earth's reflectivity can be considered fractal, and the resulting amplitude spectrum favors high frequencies (spectral blueing). If there was no preferred frequency, then you would have a "white spectrum", but as there are some frequencies with more energy, then it is called "colored".

Colored Inversion is a very fast tool which gives a precise interface for marking seismic horizons, improves the resolution and help for both stratigraphic and structural interpretation. It can also help in quantitative interpretation, reservoir characterization, field development and increase signal to noise ratio.

6.2 Methodology:

The well data and information of logs is required for the performing the colored inversion in Kingdom Software.

- The velocity is obtained from sonic log and density is obtained from density log and values of densities are obtained from density log by convolving these values.
- We get acoustic impedance by cross-matching these impedance data with the input reflection data.
- We derive a single optimal matching filter. Convolving this filter with the input data we see in figure that the result is very much similar, everywhere.
- This Empirical observation indicates that inversion can be approximated with a simple filter and that it may be valid over a sizeable region.

The wavelet is shown in figure 6.1 is extracted on the basis of the well log data that provides the true reflectivity series (i.e. compressional wave velocity and density computed into acoustic impedance logs, which are mapped into normal incidence reflectivity series). An initial guess of wavelet is convolved with reflectivity series and synthetic normal incidence trace is generated. The difference between the observed and synthetic traced is minimized using a suitable chosen norm with smoothness constraints (Mrinal K. Sen).

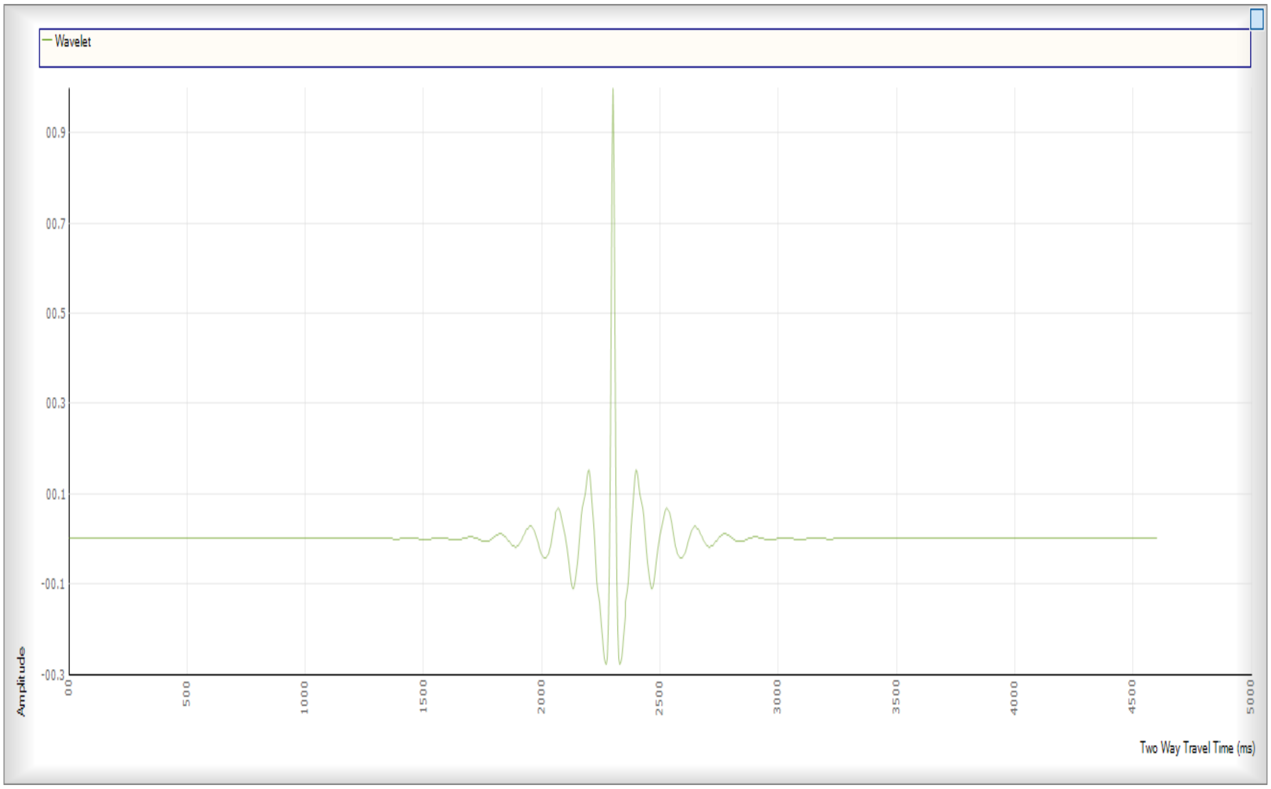


Figure 6.1: Extracted wavelet

6.3 Impedance Log Spectral Analysis:

Usually amplitude spectrum rises gently with frequency in reflectivity logs which is called "blueness" of spectrum. The amplitude spectrum of velocity * density = impedance logs can be calculated and presented on a log-log graph, from which a linear spectral slope can be projected. Here we have done Spectral Analysis for Quality Control. We have passed a satisfactory regression line on our impedance log to exclude any null data.

In a figure 6.2 impedance and frequency are plotted using Balkassar OXY-01 data to measure the svariations in physical parameters. Green line shows the impedance spectrum in log scale and blue line is fitted line through the spectrum. The impedance spectrum is shown in figure is estimated after removing source wavelet; noise must be absent; all multiple reflections must be removed; spherical spreading including all plane reflections (Ghosh 2000).

In figure 6.3, we have plotted a butter worth filter which is signal processing filter designed to gain a frequency response as flat as possible in the passband. It is also stated to as outstandingly flat magnitude filter. Amplitude is plotted on y-axis and on x-axis we have frequency, green line is a butter worth filter. In figure 6.4 we can see a modelled and desired spectrum and we can see that modelled spectrum is very near to desired spectrum. We try to modelled our amplitude spectrum as close as the amplitude spectrum of our seismic data.so this can be done through a shaping function.

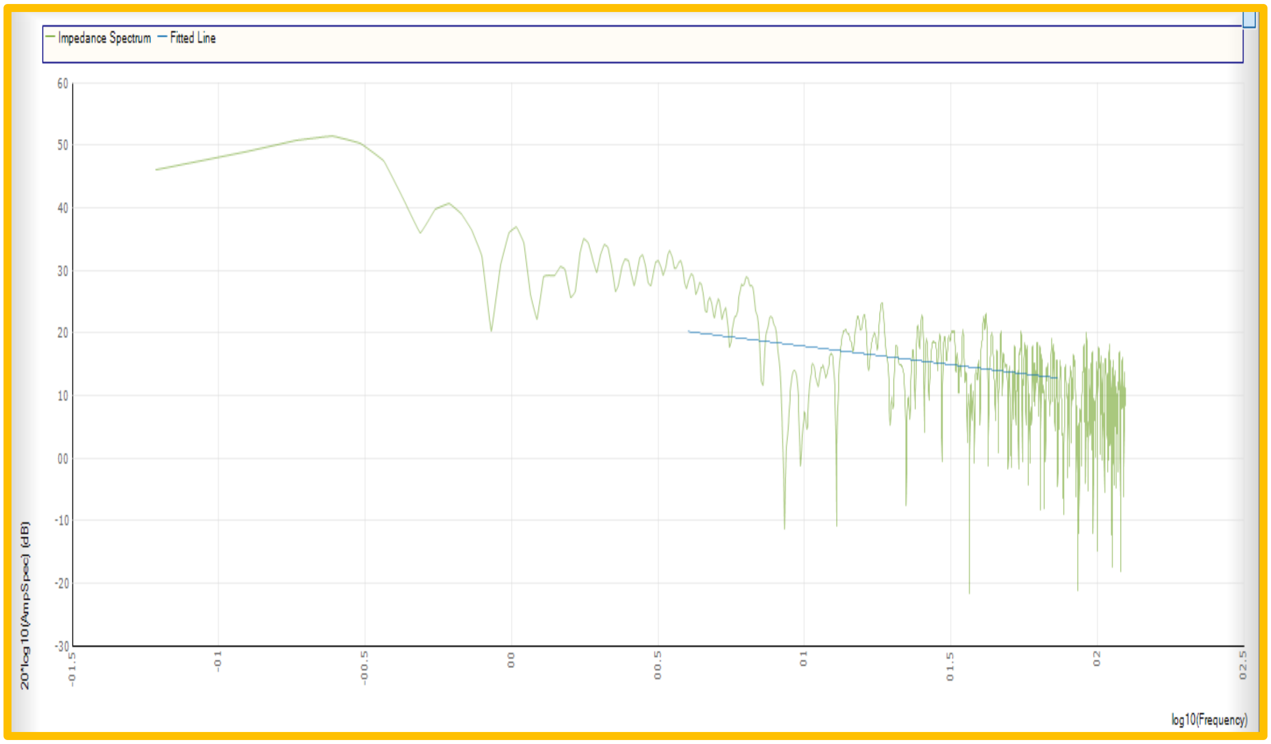


Figure 6.2: Impedance spectrum with fitted line.

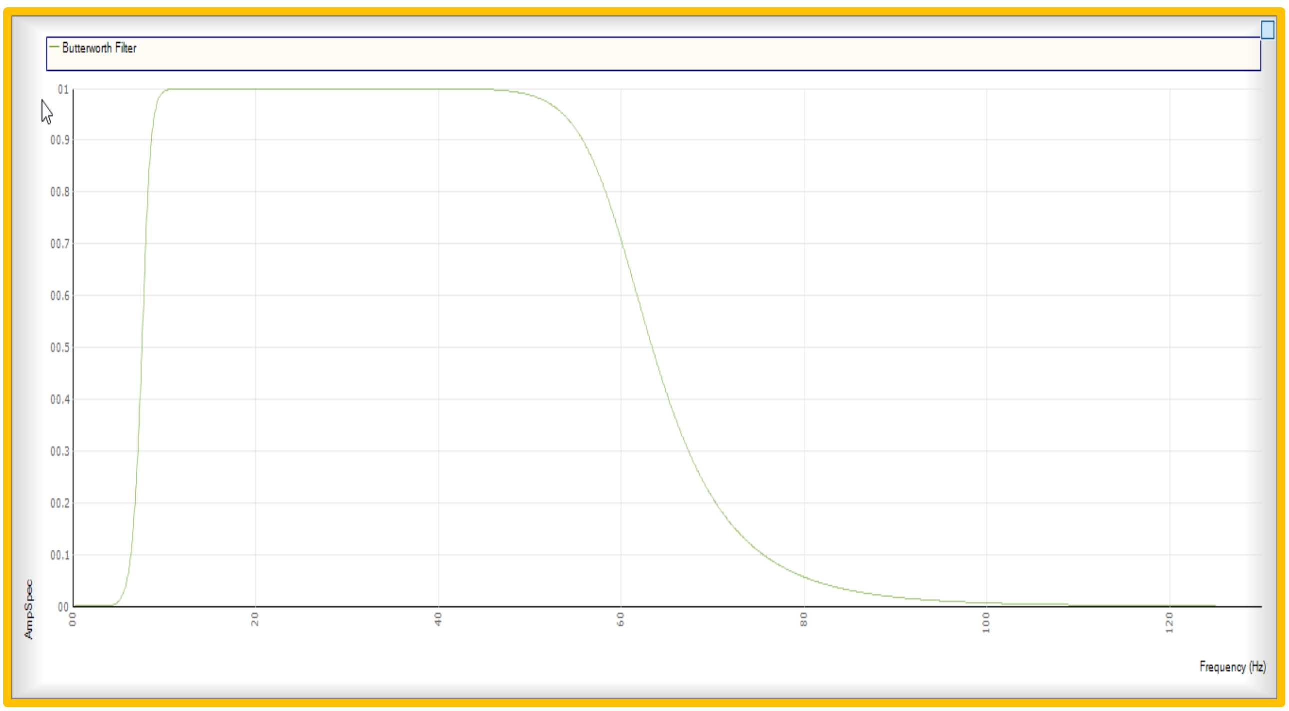


Figure 6.3: Butterworth filter

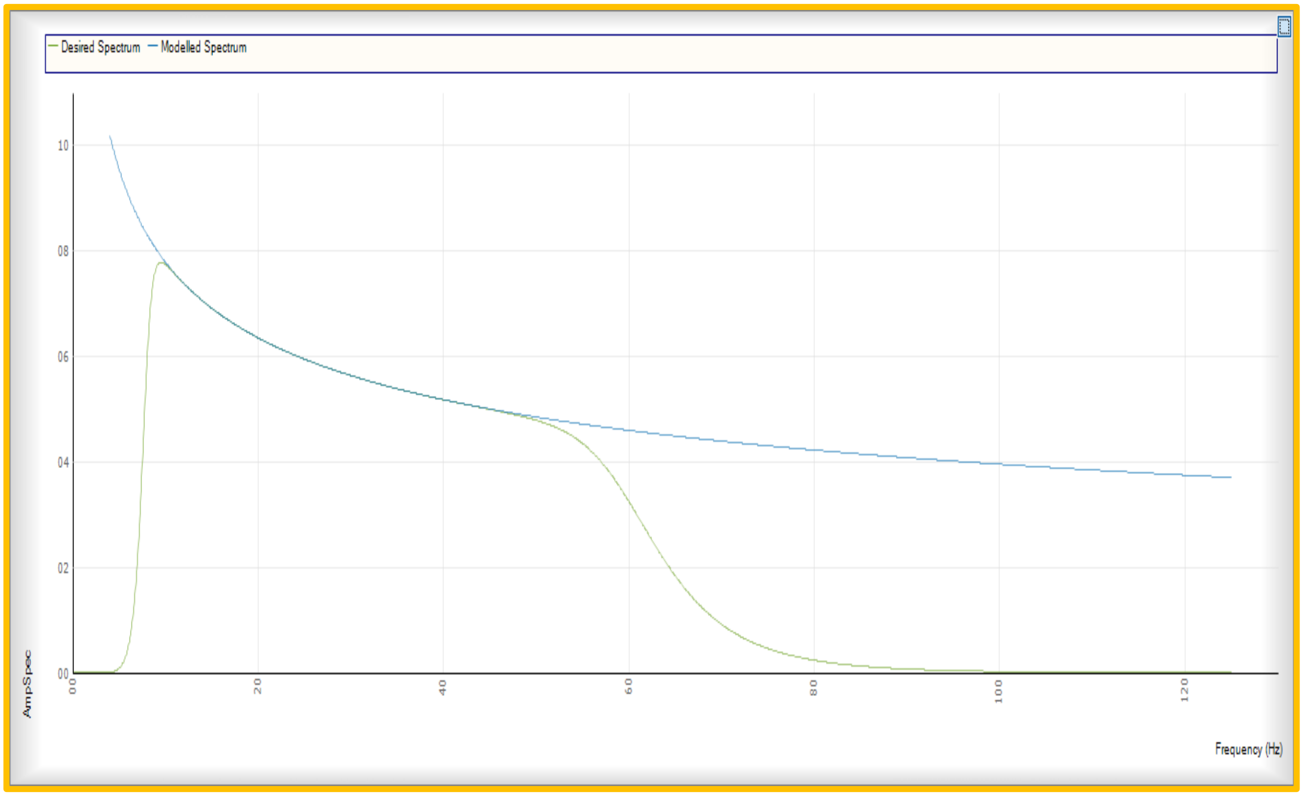


Figure 6.4 Desired and modeled spectrum.

6.4 Spectral Shaping of Seismic Data:

Figure 6.5 shows a shaping function; it may be called as pre-whitening which helps to acquire desired amplitude spectrum In figure 6.6 we have a shaped seismic spectrum which is a result of convolution of pre whiting filter, wavelet and a desired seismic spectrum. We can see now shaped seismic spectrum is very closed to our desired seismic spectrum. A seismogram for specific window (as values of acoustic impedance is obtained from well data) is developed now we develop a seismogram to invert whole section. For this purpose we convolve desired spectrum with seismic mean spectrum. After convolving seismogram with seismic mean spectrum we are able to apply it on whole seismic section. The figure 6.7 shows seismic mean spectrum and desired spectrum.It shows amplitude vs. frequency, frequency is in Hz. Seismic mean spectrum is extracted from seismic data shown with green colour while desired spectrum is in blue colour.

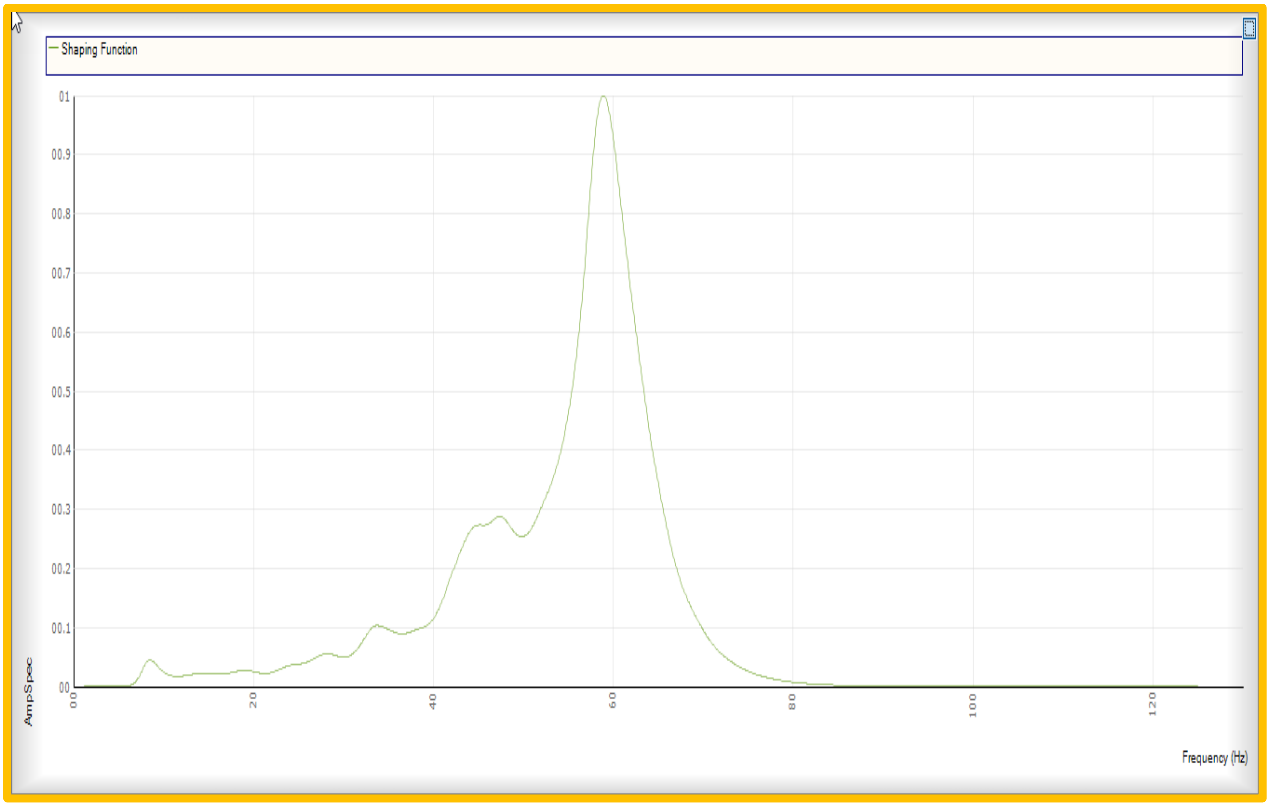


Figure 6.5: Shaping spectrum.

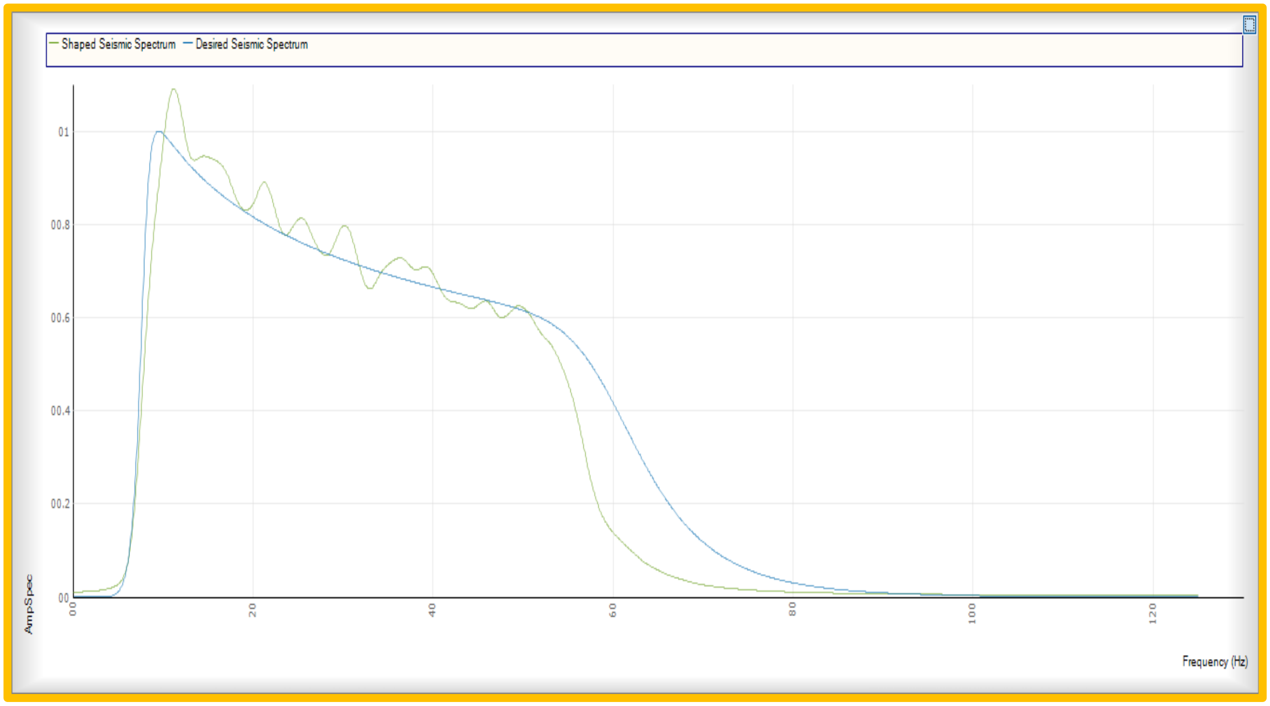


Figure 6.6: Convolution of shaped seismic spectrum and desired spectrum.

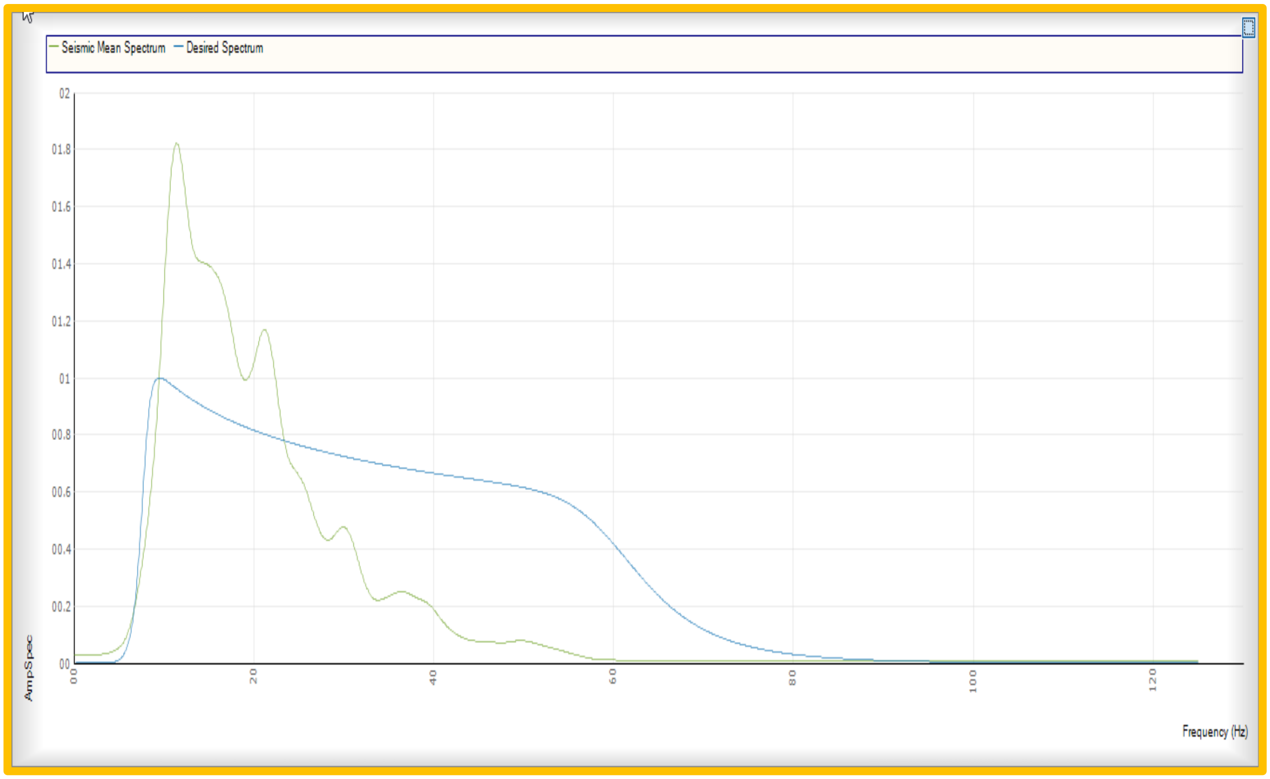


Figure 6.7: Convolution of seismic mean spectrum and desired spectrum.

6.5 Seismic Color Inversion Display:

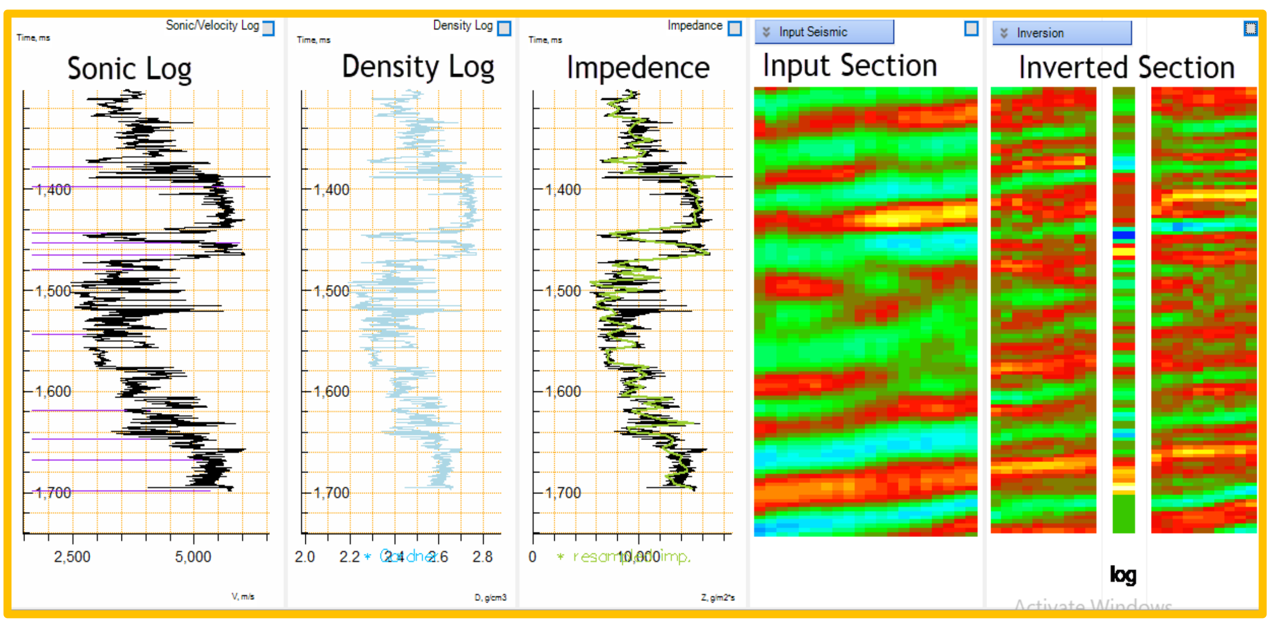


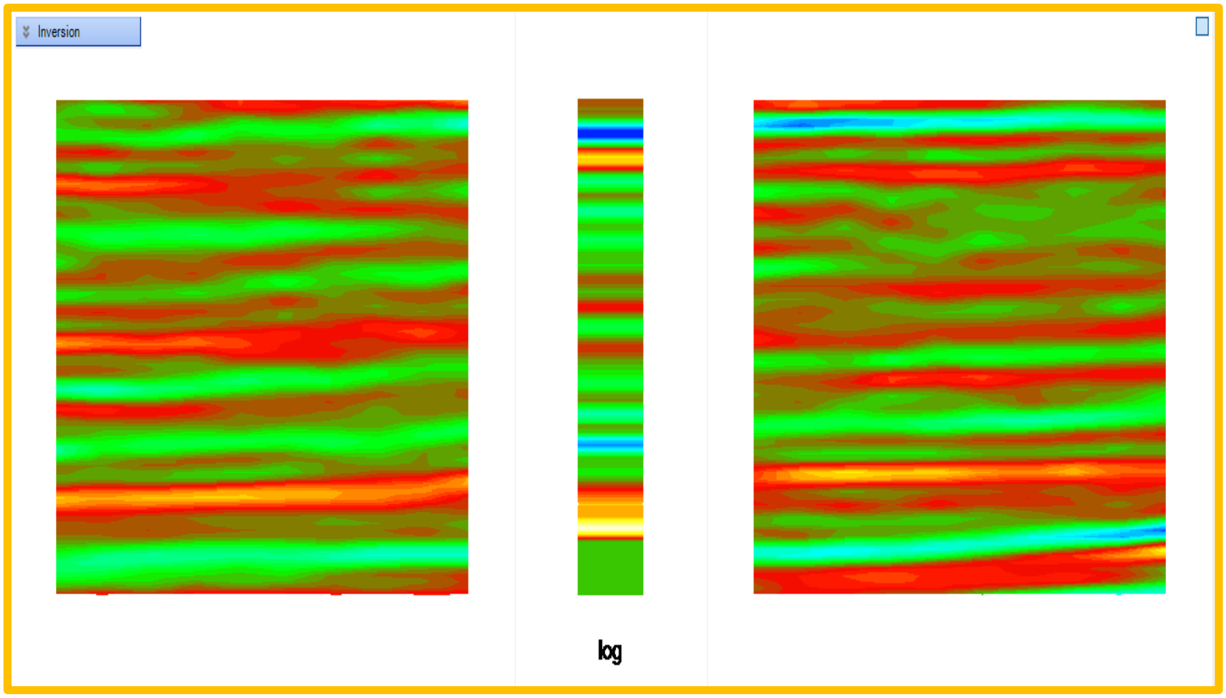
Figure 6.8: Input seismic section and inverted section along with logs.

After performing all above operations, we apply it on our seismic volume. In figure 6.7 we have a sonic log and density log which is impedance log, on impedance log we see a calibrated impedance log in green color. First we have extracted a single trace from our seismic, a single trace from impedance log and then we have incorporated it to do a color inversion. We see a resemblance in input seismic and inverted seismic data. The above window display the density and sonic log which are used to generate impedence log.In case ,if value of density logs are missing then grdner equation is used to estimate missing densities values. Gardner, is an empirically derived equation that relates seismic P-wave velocity to the bulk density of the lithology in which the wave travels. The equation reads:

$$\rho = \alpha V_{\mathrm{P}}^{\beta}$$

where ρ is bulk density given in g/cc, is P-wave velocity given in ft/s, and α and β are empirically derived constants that depend on the geology.

At the right corner of the window input seismic section is shown on left side and inverted section is shown on the right hand side. The inverted section is shown on the both sides of logs sides of the well the log is inverted to invert the seismic section. The zoomed picture of inverted section is shown in the figure given below.



6.5.1 Interpretation of Inverted seismic section:

Inverted Seiesmic section shows the seismic section w.r.t relative impedence value of each layer.

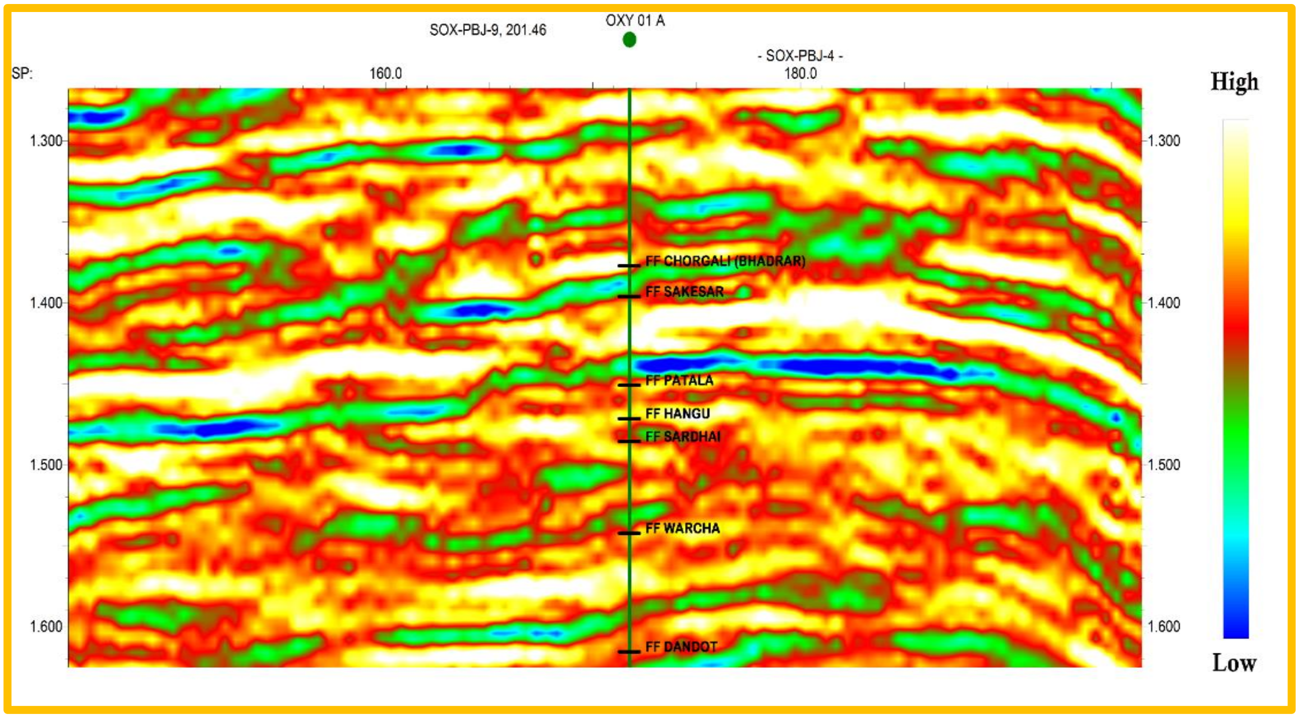


Figure 6.9:Inverted seismic section.

After convolution of seismogram with mean spectrum an inverted seismic section is generated as shown in above figures 6.9. The inverted section can be interpreted by using color bar. The white to yellow color shows high values of acoustic impedance and blue to green color shows low impedance.

The hydrocarbons accumulation is associated with low acoustic impedance. The given inverted section is shown with T-D chart and it shows Formations as well. The Formation circled in figure 6.10 is Chorgali,it yields a response of low acoustic impedance it is related to presence of hydrocarbon accumulation it is also confirmed from Petrophysical results.The Chorgali is interpreted as most producing reservoir in Balkassar area because results obtained from seismic inversion shows low values of impedance and structure formed is anticline both conditions give indication for presence of hydrocarbons.But in case of Sakesar ,inversion shows high values of impedence that is the character of tight reservoir and lower portion of Sakesar shows maturity due to the presence of shale bed.The zoomed view of figures 6.10 & 6.11 also confirms our results.

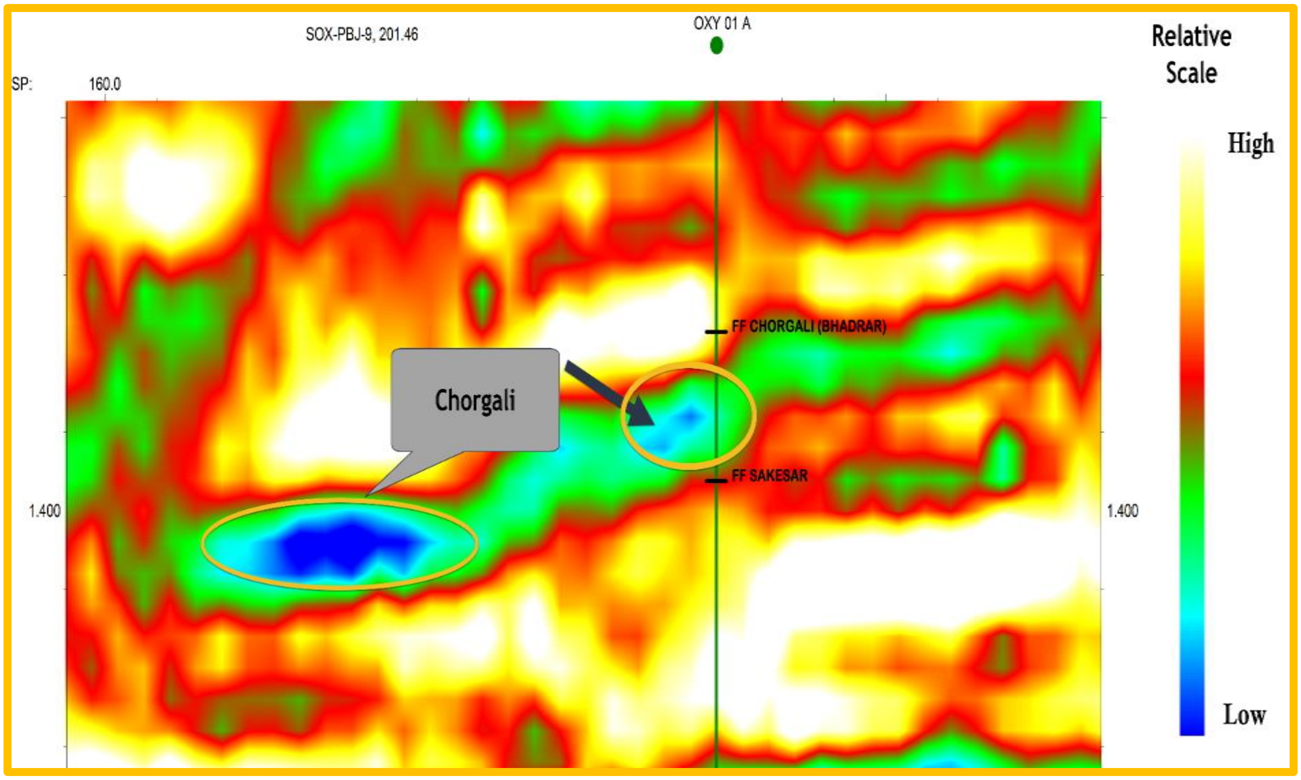


Figure 6.10: Zoomed view of inverted section of Chorgali

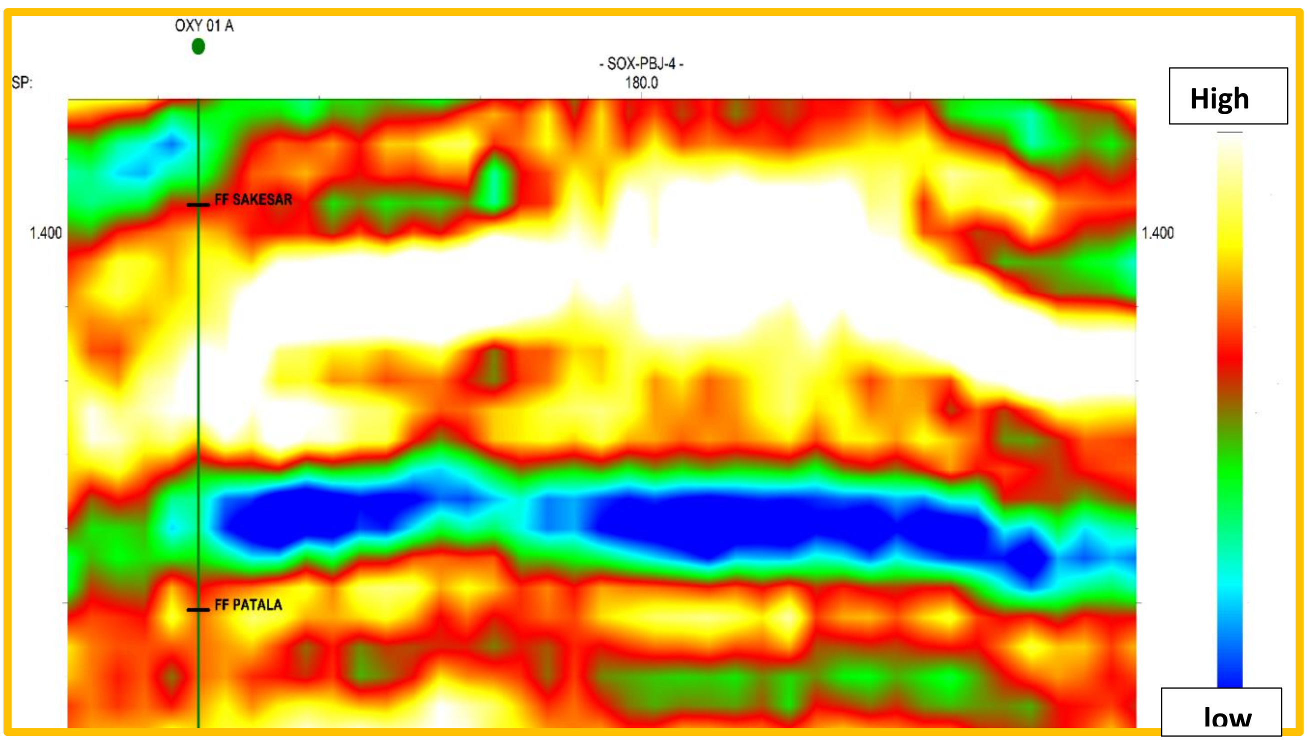


Figure 6.11: Zoomed view of inverted section of Sakesar

Conclusions:

- Subsurface seismic data interpretation of Balkassar area indicates an anticlinal “pop up”structure associated with fracturing and faulting on limbs of the anticline.
- Petrophysical analysis shows that chorgali formation have good reservoir potential while the reservoir potential of Sakesar formation is less & is not an economical due to less porosity.
- Facies analysis shows that reservoir rocks are mainly comprised of limestone with minor shaly limestones packages.
- The reservoir characterization is distributed over the whole seismic survey through seismic inversion technique, which also supports the results of petrophysical analysis by showing low impedence value in chorgali which is the character of reservoir potential and high impedence value in sakesar that indicates the character of tight reservoir (low porosity).

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